33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-2.152 (2006)

Investigation of the poloidal GAM induced density fluctuation at TEXTOR

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1 Introduction

Over the last years the investigation of zonal flows (ZF) and geodesic acoustic modes (GAMs) have become a hot topic in plasma physics [1]. Zonal flows are symmetrical in terms of poloidal and toroidal mode number ($m = 0, n = 0$). They are the consequence of fluctuations in the plasma potential. They give rise for fluctuations in the electric field and therefore influence the radial $E \times B$ shearing rate. A temporary increase in the shearing can under certain conditions trigger a transition from L-mode confinement to improved confinement by suppressing the ambient turbulence. On the other hand the ambient turbulence must have a certain level to allow for the existence of ZFs and GAMs. This is one reason that zonal flows are widely investigated and are supposed to change the transport properties of plasmas.
In fusion devices like a tokamak zonal flows are accompanied by pressure side bands due to curvature effects. These density perturbations (GAMs) are supposed to have $m = 1, n = 0$ structure and oscillate at a frequency which scales with the ion sound speed. The density fluctuations should therefore be enhanced at $\theta = 90^o$ and vanish in the equatorial plane at $\theta = 180^o$ [2]. The GAMs are localized at the plasma edge mostly in the region $0.80 \leq r/a \leq 0.95$. The radial wavelength of the GAMs is estimated to be in the order of 10-20 ion gyro radii. Indications for GAMs are also found more deep in the plasma at low rational q–surfaces [3]. Furthermore several experiments report on a increased amplitude of the GAMs with the safety factor at the edge (q_a). GAMs are mostly observed at $q_a \geq 4.3$[4].
At TEXTOR a cross correlation O–mode reflectometry system with a frequency range $26 \leq f \leq 37$ GHz is in operation [5]. The system is capable to measure the plasma edge for electron densities in the range $0.86 \leq n_e \leq 1.7 \times 10^{19}$ m^{-3}, which, for the main plasma conditions of TEXTOR in these experiments, corresponds to $0.57 \leq r/a \leq 0.9$. The system is equipped with two antennae arrays, one in the low field side midplane, the other at top of the vessel. Each array consists of five antennae (see fig. 1). It allows the measurements of short range cross correlations within each of the arrays as well as long range cross correlations between both antennae arrays, simultaneously.

2 Observations at TEXTOR

Experiments at TEXTOR were performed for ohmic plasmas for $q_a = 3.0$ and $q_a = 4.8$ respectively. In a further experiment at $q_a = 3.0$ the tangential neutral beam injection power into the plasma was varied to see if the ambient turbulence is modified and has an impact on the GAMs. In the spectral representation of the reflected amplitude and the coherence the footprint of the GAM is a single nearly monochromatic peak in the frequency range $9 \leq$

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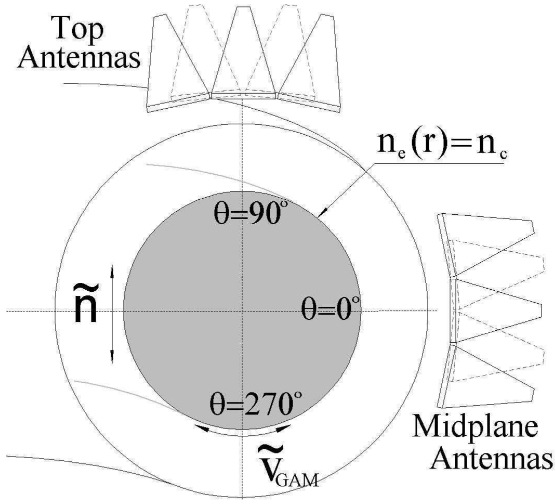

Figure 1: *Poloidal cross section with reflectometer antennae and a sketch of the velocity ($\tilde{v}_{GAM}$) and density ($\tilde{n}$) oscillations due to the GAM.*

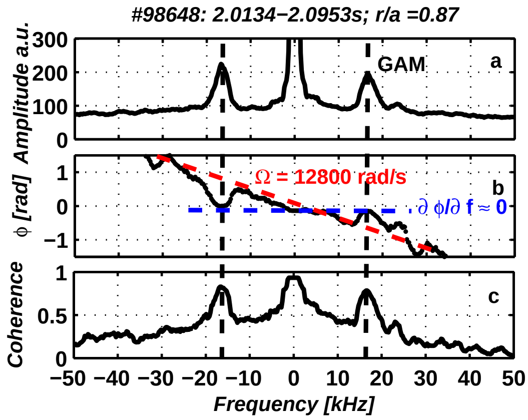

Figure 2: *Spectra of amplitude (**a**), cross phase (**b**) and coherence (**c**) obtained from two top antennae. In (**a**) and (**c**) a single peak at 16.7 kHz is seen. In (**b**) the change of the average slope by the GAM is shown.*

$f \leq 25$ kHz (see fig. 2). In the cross phase spectrum (fig. 2b) the phase difference at the GAM frequency is negligible. However a clear slope indicates the propagation of the ambient turbulence at a speed of $\Omega = 12.8$ krad/s. Since at f_{GAM} $\partial\phi/\partial f \approx 0$ the propagation time yields $\Delta t = 0$, too. This indicates that (i) the GAM has no net rotation and (ii) the GAM must have a low m-number. Also in the coherence spectrum obtained from two antennae a single monochromatic line at f_{GAM} is visible. By varying the frequency of the reflectometer the frequency scaling and the radial localization of the GAM is studied. Since the frequency scaling with ion sound speed c_s implies also a change of the GAM frequency with the ion mass, Deuterium, Hydrogen and Helium plasmas are investigated. Since the GAM is mainly detected at the plasma edge, the Artsimovich equation for the estimation of the ion temperature T_i is used. Electron temperatures are determined from a standard electron cyclotron emission (ECE) diagnostic. As seen in fig. 3 the GAM frequency increases linearly with the square root of the temperature described by:

$$f_{GAM} = \frac{k}{2\pi R_0} \cdot c_s, \quad c_s = \sqrt{\frac{T_e + T_i}{M_i}} \tag{1}$$

The measured data for the deuterium plasmas are located between the scaling for deuterium and hydrogen reflecting the different H/D ratio.

For the determination of radial position of the GAMs, the amplitude of the GAM from the amplitude spectrum is deduced and presented in fig. 4 versus r/a. Here the reflection layer is calculated from density profiles obtained from a nine chord HCN interferometer. Beside a few data points at $r/a \approx 0.72$ the GAM is localized within $0.8 \leq r/a \leq 0.91$. The data where obtained for ohmic plasmas with $3.0 \leq q_a \leq 3.5$. The radial localization is in agreement with observations at AUG [7] and DIII-D [6]. The GAM amplitude decreases radially within 1-2 cm. Outside $r/a = 0.91$ no GAMs are observed. The observed large scatter of the amplitude data is an indication of the modulation of the GAM amplitude. From a sliding FFT a modulation level of ≈ 100 % in the GAM amplitude is found, whereas at the same time

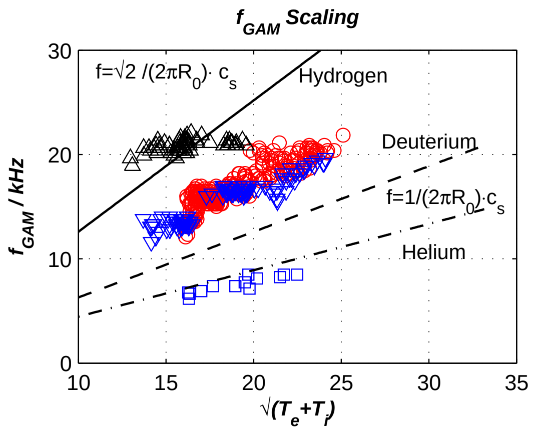

Figure 3: *Scaling of the GAMs with* $\sqrt{T_e + T_i}$. *The different fits are due to different ion mass.* (□) *denotes the predominately Helium and* (△) *the Hydrogen plasmas. Other symbols denote Deuterium plasmas with different H/D–ratios.*

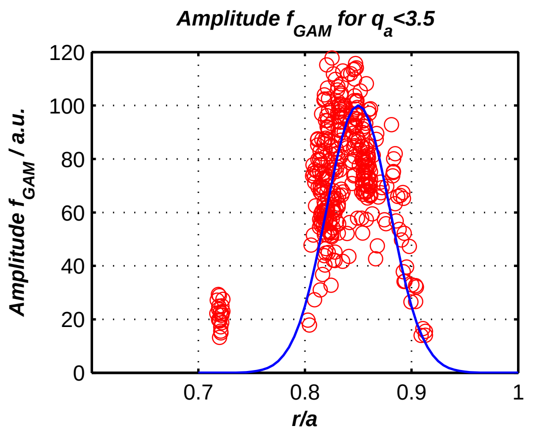

Figure 4: *The amplitude of the GAM as obtained from the amplitude spectrum versus* r/a. *To guide the eye, the localization can be described by Gaussian function (blue curve) centered at* $r/a = 0.85$.

the GAM frequency, the local density and temperature are kept constant. This is an indication for a burst like structure of the GAM. The burst duration of a single GAM is estimated to $t_b \approx 2$ ms. For the investigated pulse #98648 the average time between two burst is ≈ 2.5 ms. The observed intermittency is most likely due the interaction of the ambient turbulence with the GAM. Similar observation were reported from AUG [7]. The analysis of the GAM amplitude at the midplane position yields no or even very small values, whereas the GAM amplitude at the top position is very pronounced (see fig. 5). The difference in the amplitude is more than a factor 10. However the frequency as well as the full width at half maximum are equal at $\theta = 0^o$ and $\theta = 90^o$. To see whether the GAM amplitude is also pronounced at $\theta = 270^o$ a pulse with reversed magnetic field is performed. Also in this case the GAM amplitude is pronounced at the top position. The observation are in agreement with the theoretically supposed sine dependence [1] of the GAM induced density fluctuations on the poloidal angle θ.

$$\frac{\tilde{n}}{n_c} = -\left(\sqrt{2}k_r\rho_i\frac{e\tilde{\Phi}}{T_e}\right) \cdot sin(\theta) \tag{2}$$

From the far correlation (see fig. 6), between top and midplane antennae the obtained coherence is very small, however the high contrast in fig. 6b is a further justification for the large poloidal wavelength of the GAM. The observations indicate a poloidal mode number $m = 1$ for the GAM. More over a satellite peak close to the GAM and at somewhat higher frequency ($f \approx 20$ kHz) is visible (see fig. 6b). It seems that this peak has the same poloidal structure as the GAM. Similar observations on satellite peaks are reported from T–10 [3].
From the analysis of the cross phase the contribution of the GAM induced density fluctuations $(\tilde{n}/n_c)_{GAM}$ the contribution to the total density fluctuations $(\tilde{n}/n_c)_{tot}$ is determined [5]. For this estimation the radial wavelength from the measurement at T–10 [3] is used, yielding $\lambda_r \approx 0.05$ m. This is justified since TEXTOR and T–10 are similar in geometrical dimensions and plasma parameters. For the GAM maximum in the radial localization, at $\theta = 90^o$ $(\tilde{n}/n_c)_{GAM} \approx 0.09 \pm 0.009$ % is estimated and $\approx 0.008 \pm 0.008$ % is found for $\theta = 0^o$. Compared to the total fluctuation level at this position the GAM contributes with

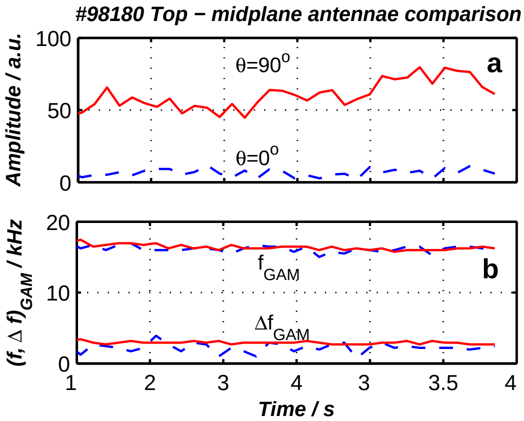

Figure 5: ***(a)*** *Comparison of the GAM–amplitude at top (solid) and midplane (dashed) position.* ***(b)*** *Center frequency and FWHM of the GAM peak, showing that top and midplane antennae observe the same phenomena.*

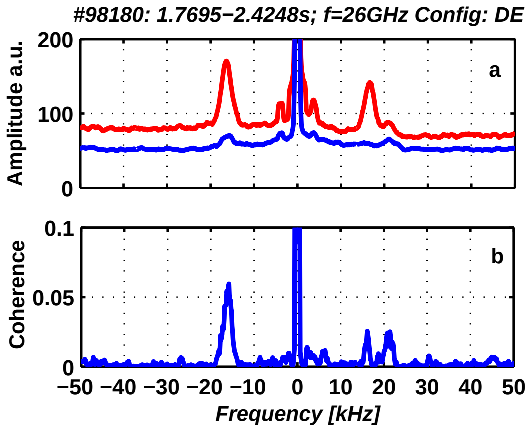

Figure 6: *Far poloidal correlation over* $\Delta\theta = 90^o$*. The GAM is visible in amplitude* ***(a)*** *and coherency* ***(b)*** *spectra at* $\approx$ 17*kHz. Beside the GAM a high frequency satellite is observed in the right wing of the spectrum.*

$\tilde{n}_{GAM}/\tilde{n}_{tot} \approx 7.5$ % at $\theta = 90^o$ and ≈ 0.5 % at $\theta = 0^o$.

As already mentioned the GAM has not net rotation. It oscillates with the GAM frequency. The effect of the GAM becomes visible in the modulation of angular rotation of the ambient turbulence. This is performed by analyzing the cross correlation for sample intervals which are twice less than the GAM period. It gives a modulation of the angular rotation of the ambient turbulence by 5–10%. The modulation influences the effective shearing rate and is in the order of the decorrelation rate of the ambient turbulence.

3 Summary

With the reflectometry system at TEXTOR the properties of the geodesic acoustic mode are studied. The scaling of f_{GAM} with the ion sound speed is verified for a large range. The GAM at TEXTOR are localized at $0.8 \leq r/a \leq 0.9$ and appears in burst with a duration of ≈ 2 ms. The GAM is visible only at $\theta = 90^o$ and 270^o. The GAM is almost not visible in the midplane as supposed from theory. From the phase fluctuations a contribution of ≈ 7.5 % to $(\tilde{n}/n_c)_{tot}$ is found at the top position. The far correlation and a $\partial\phi/\partial f \approx 0$ support the low m-number of the mode. The influence of the GAM on the ambient turbulence is observed in the frequency spectrum of the time delay between different antennae.

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