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# Geodesic Acoustic Mode – Radial Extension and Interaction with magnetic Islands

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TEXTOR– and the T-10–Teams
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## Introduction

The investigations of zonal flows (ZFs) and geodesic acoustic modes (GAMs) have become a hot topic in plasma physics [1, 2] over the last years. They are detectable with high temporal and spatial diagnostics e.g. Langmuir probes, reflectometry. Zonal flows are symmetrical in terms of poloidal and toroidal mode number ($m = 0, n = 0$) and GAMs have an $m = 1, n = 0$ structure. They are observed at the plasma edge for $0.80 \leq r/a \leq 0.95$ as a consequence of fluctuations in the plasma potential. The potential fluctuations induce fluctuations in the radial electric field and 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 or trigger the transport properties of plasmas.
During the last years monochromatic lines in the complex amplitude spectrum from reflectometry measurements are observed up to half plasma radius ($r/a \approx 0.6$). Specially at T-10 the existence of GAM like lines at rational surfaces is observed [3]. These lines appear in a frequency range which is also known from the GAMs.
The paper reports on the radial extension of GAMs at TEXTOR ($R_0 = 1.75$ m, $a = 0.47$ m) and compares it with earlier observations. In the second part the properties of GAMs, as observed on TEXTOR [4] and other devices [5, 6], are compared and discussed with the properties of the recently found GAM like events at the separatrix of magnetic islands. A recent theory predicts spontaneous ZFs at the separatrix of large islands. The dynamic ergodic divertor at TEXTOR is used for the generation of $m/n = 2/1$ islands and allows a systematic study of those GAMs.
The investigations are done with correlation reflectometry as diagnostic for the detection of GAMs at TEXTOR.

## Diagnostic Setup

At TEXTOR a cross correlation O–mode reflectometry system with a frequency range $26 \leq f \leq 37$ GHz is in operation [7]. 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 $0.4 \leq r/a \leq 0.9$. It can operate in fixed frequency mode as well as in hopping frequency mode. 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. 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.

## Radial Extension of GAMs

The plasma parameters are chosen as $300 \leq I_p \leq 350$ kA, $B_t = 2.25$ T. The line averaged density (flat top) is in the range $1.5 \times 10^{19} \leq \overline{n_e} \leq 2.5 \times 10^{19}$ m$^{-3}$ and varied on a shot to shot basis. The pulses are ohmically heated. The $q = 2$ surface is estimated to be at $2.06 \leq R_{q=2} \leq 2.08$ m which corresponds to $r/a \approx 0.6$ and can be accessed by reflectometry for $\overline{n_e} \leq 2.0 \times 10^{19}$ m$^{-3}$. In fig. 1 the complex amplitude spectrum is shown for $\overline{n_e} = 2.0 \times 10^{19}$ m$^{-3}$ and in the frequency range of interest for different reflection layers ($R_c$). The upper left subplot shows the $R_c$ color coded. The subplots (b-f) show the evolution of the complex GAM amplitude ($A_{GAM}$). The color codes in these subplots correspond to the reflection layer. It is seen that the amplitude of the GAM has a maximum at a certain position and that the frequency increases towards the plasma center. The observed frequency as deduced from the amplitude spectrum agrees with the already proven $f_{GAM} \propto \sqrt{(T_e + T_i)/M_i}$ scaling [4]. Also the long distance ($\theta = 90^o$) correlation could be verified. Furthermore a peak at $f = 14.5$ kHz is found, which does not change in amplitude and frequency.

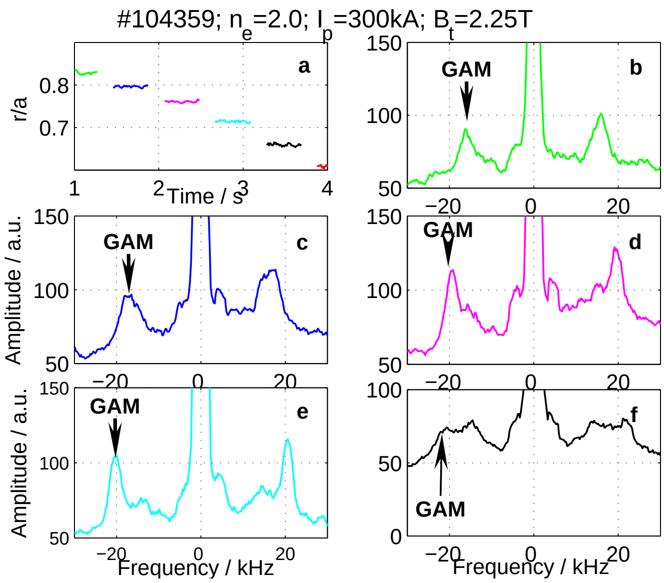


Figure 1: Evolution of GAMs for different $R_c$. The upper left figure shows the different radii, where the complex spectrum are measured.

For $\overline{n_e} = 1.5 \times 10^{19}$ m$^{-3}$ $R_c$ covers the $q = 2$ surface. For $\overline{n_e} = 3.5 \times 10^{19}$ m$^{-3}$ the reflection layer covers $0.86 \leq r/a \leq 0.93$ m no indications of GAMs are found. In fig. 2 the complex amplitude of the GAM as function of $r/a$ is shown. It is well seen that in the vicinity of the q=2 surface the $A_{GAM}$ decreases. Also the a noticeable deviation from the frequency scaling is observed when the $q = 2$ surface is approached. Furthermore the radial range of the GAM moves inward with increasing $\overline{n_e}$. The observations suggest that the GAMs are related to a certain range of local plasma density and temperature and not to a particular rational surface as suggested earlier [3]. The damping of ZFs and GAMs depends on the collisionality ($\nu^*$) as reported earlier [8]. The observed data suggest that towards the plasma edge the GAMs disappear when the damping overcomes a threshold of $\gamma \propto \nu^* \cdot \varepsilon > 1$, here $\varepsilon$ is the aspect ratio.

**Search for GAMs in the vicinity of large magnetic islands**

A recent theory [9] predicts the onset of spontaneous ZFs and GAMs at the separatrix of the island when the $\Delta' w \geq 1$. A small amount of magnetic energy is transformed into kinetic energy which can generate oscillating velocity fields at the separatrix. For several pulses the DED is applied in 3/1 configuration with $I_{DED} \leq 2$ kA in dc operation during the flat top of the discharge, where it generates a locked $m/n = 2/1$ island at $R = 2.05$ m with a width of $0.08 \leq w \leq 0.10$ m [10]. After switch off of the DED the mode unlocks and starts to rotate again. The island separatrix can be studied for the locked mode case at the O-point (top antennae) and the X-point (midplane antennae).

For two cases with similar $R_c$, one without and one with $m/n = 2/1$–island the amplitude at the GAM frequency is measured. In the case with $m/n = 2/1$–island $R_c$ is close to the separatrix of the island. As seen in fig. 3 at the frequency of the GAM strong lines are observed when the island is generated. Compared to the case without island the amplitude is increased by a factor two. The measured frequency agrees within 15% with the $f_{GAM}$–scaling. From a frequency scan

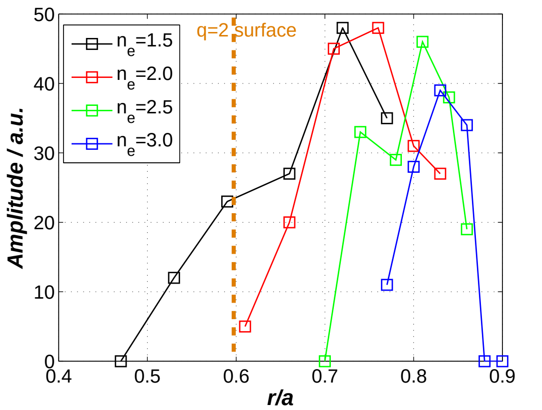


Figure 2: GAM amplitude as function of $r/a$ and position of $q = 2$ surface.

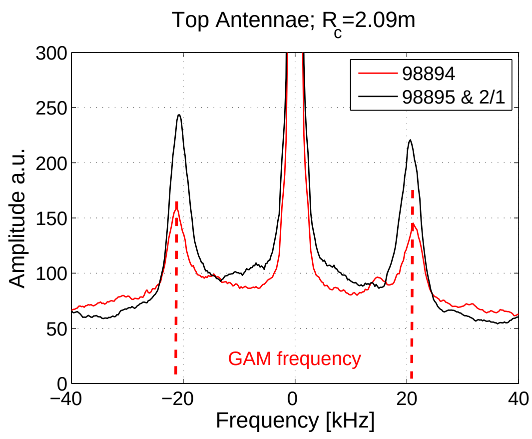


Figure 3: A line at $f_{GAM}$ is observed close to the separatrix of the $m/n = 2/1$–island.

of the reflectometer the radial width of the GAM at the separatrix is determined to $\Delta R \approx 0.03$ m. To prove further GAM properties, the coherence for the long distance correlation and the crossphase for $\theta = 5.2^o$ are analyzed (see fig. 4). The upper subplot shows the deviation from the plasma rotation $v_\perp^{plasma}$ as indicated by the black dashed line at the GAM frequency. This is an indication that the observed structure has no net rotation. In the lower subplot the coherence for the long distance correlation of $\theta = 90^o$ is shown. As expected for GAMs a correlation is observed. As a last test the fluctuations in the $\Delta t$ spectrum from the two top antennae are analysed. The observed peak at $f = 20$ kHz confirms a velocity oscillation which the assumed for GAMs and ZFs. This indicates that the structure observed close to the separatrix is most likely a GAM. Its amplitude increases by the existence of the $m/n = 2/1$–island.

## Conclusion

The paper investigates the radial extension of the GAMs. It is shown that the GAM is not related to rational surfaces. The paper supports the that GAMs are detectable only when $\nu^* \cdot \varepsilon \geq 1$. Towards the plasma center the level of the ambient turbulence seems to regulate the GAM. The radial width of the GAM region decreases with increasing $\overline{n_e}$. Evidence for a GAM close to the separatrix of a $m/n = 2/1$ island is found. The GAM properties, as long distance correlation and velocity oscillations are analyzed and support the theoretical predictions of zonal flows and GAMs at the separatrix of large island. Furthermore the radial width is estimated to $\Delta R \leq 0.03$ m, which falls into the range of the expected radial width of GAMs of 0.03 m to 0.06 m.

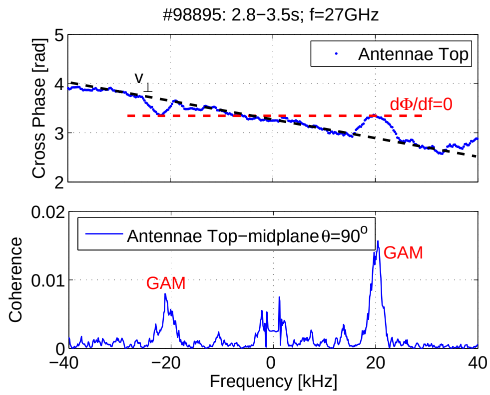


Figure 4: Crossphase and coherence for a GAM at the separatrix of the $q = 2$ island

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