EUROFUSION CP(15)05/90

C. Silva et al.

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(22nd June 2015 – 26th June 2015)
Lisbon, Portugal

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Experimental investigation of geodesic acoustic modes on JET using Doppler reflectometry

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Introduction

Geodesic acoustic modes (GAMs) are characterized by a symmetric potential structure in the poloidal and toroidal directions and a rapidly varying radial structure with finite wavelength. Because of their small radial structure, the E×B shearing rate due to GAMs can be important before and during the L-H transition when the mean shear flow is modest [1]. Recently, the influence of isotope mass on the GAM amplitude has been studied [2] showing a systematic increase in the GAM amplitude during the transition from H to D dominated plasmas. Consequently, understanding GAMs may yield important implications for the dynamics of the L-H transition.

This contribution focuses on the characterization of GAMs in the edge plasma of JET Ohmic discharges using mainly Doppler reflectometry. Coherent oscillations consistent with the GAM theoretical predictions are identified and characterized. In addition, the dependence of GAM amplitude on the driving and damping mechanisms are investigated.

Measurement technique

Doppler reflectometry is a microwave diagnostic for density fluctuation measurements that measures the radially localized propagation velocity and fluctuation level of intermediate wave number turbulent structures. This diagnostic has contributed extensively to the characterization of coherent oscillations such as the GAM [e.g. 3]. Motion of the density turbulence at the cutoff layer will induce a Doppler frequency shift (f_D) in the reflected signal given by $f_D = u_\perp k_\perp/2\pi$, where $u_\perp = v_{E\times B} + v_{phase}$ is the perpendicular velocity of the turbulence moving in the plasma [e.g. 4]. For the vertical target (VT) configuration (plasmas with both

* See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia

divertor strike points on the vertical targets) the JET correlation reflectometer [5] works for Doppler backscattering as a deliberate oblique angle between the launched beam and the normal to the plasma cutoff layer is created. The scattering wavenumber of the density fluctuations is determined via ray tracing [6]. For the data presented here the typical probed $k_\perp$ is ~ 3 cm^{-1}. The Doppler frequency is obtained from the complex amplitude spectrum of the reflectometer in-phase ($I = A\cos\varphi$) and quadrature ($Q = A\sin\varphi$) signals. The instantaneous Doppler shift is estimated directly from the rate of change of the reflectometer phase signal $d\varphi/dt$, where the phase is obtained from $\varphi(t) = \tan^{-1}[Q(t)/I(t)]$ and the instantaneous signal amplitude from $A(t) = [I^2(t)+Q^2(t)]^{1/2}$. The JET correlation reflectometer consists of two X-mode fast frequency hopping channels launched from the LFS midplane designed for normal incidence. Each channel can be pre-programmed with a specified launch frequency pattern, which is repeated continuously throughout the discharge, allowing a radial scan of the measurement location. For the data presented here, channel 1 (master) was set to a 11 point frequency sweep (from 74.6 to 92.6 GHz), while channel 2 (slave) had a 15 point frequency sweep of 2 ms duration around each master frequency.

GAM identification and location

Experiments were performed in Ohmic vertically-shifted plasmas for different values of plasma current and density. Figure 1 shows the temporal evolution of the line-averaged density and master probing frequency, together with the spectrogram of the master signal phase derivative. As illustrated, the frequency spectrum of the phase derivative is sharply peaked at the GAM frequency (f_{GAM}), which follows the local plasma temperature (the solid line shown in the spectrogram indicates the calculated $f_{GAM}=c_s/(2\pi R)$, where $c_s=\sqrt{[(T_e+T_i)/m_i]}$ assuming $T_e=T_i$. The local T_e given by the ECE diagnostic is used). The GAM amplitude has been estimated as: (i) amplitude of the $d\varphi/dt$ spectrum at f_{GAM}; and (ii) rms of the $d\varphi/dt$ bandpass filtered around f_{GAM}. A good agreement is found between the two approaches. Figure 2a shows the electron density radial profile, obtained with the profile reflectometry system, for two periods of the discharge #87808 (t = 12 and 15 s) with different densities. The location of the master probing frequencies is also shown

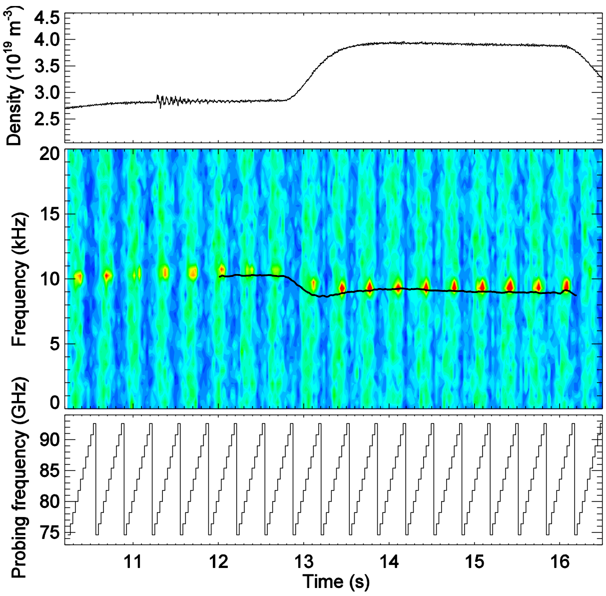

Figure 1: Temporal evolution of the line-averaged density, spectrogram of the master signal phase derivative and master probing frequency for discharge #87808 (I_p = 2.75 MA, B_T = 3 T).

(symbols). Figures 2b,c present the GAM amplitude and frequency respectively, while figure 2d shows the radial profile of the mean perpendicular velocity. As illustrated, GAMs are generally most intense in the edge density gradient region with a radial extension of about 2 cm, coinciding with the location of the E_r well. The GAM has a constant frequency with radius, not varying with the local temperature (the calculated f_{GAM} using the local T_e is indicated by the solid line in figure 2c). The GAM rms $E_r \times B$ flow velocity is up to 1.5 km/s, corresponding to about 50% of the local mean value.

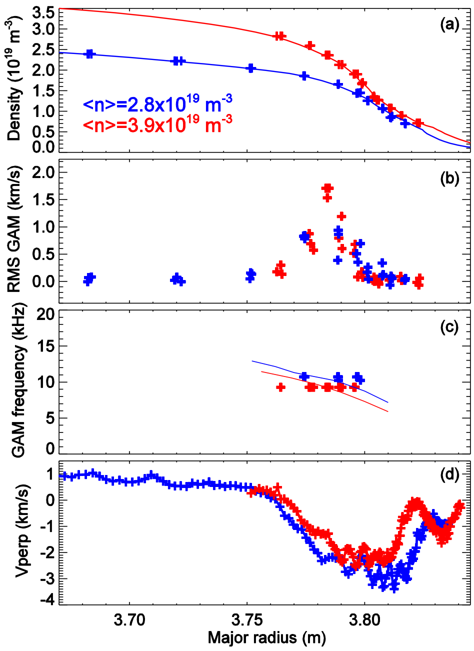

Figure 2: Radial profiles of density (a), GAM amplitude (b) and frequency (c) and mean perpendicular velocity (d) for two discharge periods with different densities (#87808).

GAM damping and drive

There are two factors determining the magnitude of the GAM: its drive and damping. Collisionless damping strongly depends on the safety factor ($\gamma \propto \exp[-q^2]$), while the collisional damping has a weaker q dependence ($\gamma \propto \nu_{ii}/q$). A series of six Ohmic discharges where performed in hydrogen for different values of plasma current ($1.5 < I_p < 2.75$ MA) and line-averaged density ($1.5 < n < 4 \times 10^{19}$ m^{-3}). Figure 3 shows the GAM amplitude (maximum of the GAM rms value across the radial regions scanned by the correlation reflectometer) as a function of the expected GAM damping rate. The GAM amplitude is observed to decrease with q, in contradiction with the anticipated for the collisionless damping. Furthermore, no decrease of the GAM amplitude with ν_{ii}/q is observed. GAMs on JET Ohmic plasmas appear to be regulated by the turbulence drive. Figure 4 shows the density and temperature inverse scale length ($1/L_{n,T}$) for different discharge densities (the inverse gradient scale lengths are the drive terms for drift-wave type turbulence). For the lowest discharge density a smaller $1/L_{n,T}$ is observed and no GAMs are detected. In general, the density fluctuation level, as well as the edge plasma density and temperature inverse scale lengths, increase with plasma current and line-averaged density, concurrent with the enhancement of the GAM amplitude.

Isotope effect

The impact of isotope mass on GAM amplitude has also been investigated on JET. As illustrated in figure 5, the GAM amplitude is apparently larger for deuterium plasmas in agreement with previous findings in TEXTOR [2] and FT-2 [7] suggesting the importance of multi-scale physics for unravelling the physics of the isotope effect in fusion plasmas.

However, the limited dataset available and the complex dependence of the GAM amplitude on plasma parameters prevent a more definitive conclusion.

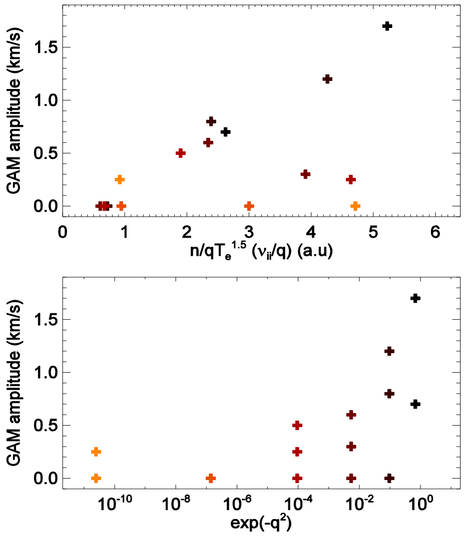

Figure 3: Dependence of the GAM amplitude on the collisionless and collisional GAM damping (colour scheme follows plasma current value).

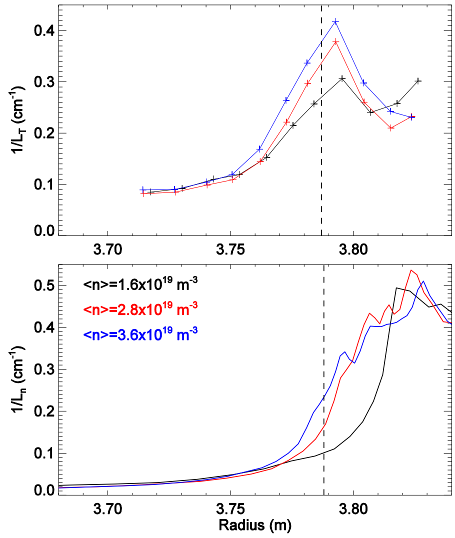

Figure 4: Density and temperature inverse scale-length for different discharge densities. The dashed vertical line indicates the radial location of the GAM maximum amplitude.

Summary

GAMs have been investigated in the JET edge plasma for Ohmic discharges using mainly Doppler reflectometry. GAMs were found to be located in a narrow layer at the edge density gradient region with amplitude corresponding to about 50% of the mean local perpendicular velocity value. GAMs on JET appear to be regulated by the turbulence drive rather than by their damping rate. Finally, it was shown that the GAM amplitude is slightly larger in deuterium than in hydrogen plasmas.

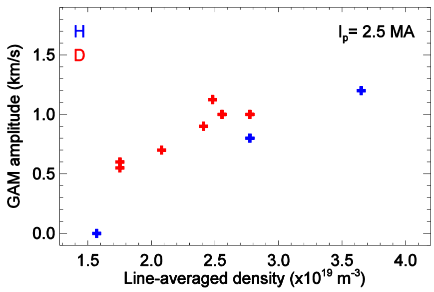

Figure 5: Dependence of the GAM amplitude on the plasma density for hydrogen and deuterium plasmas.

References

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Acknowledgements

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. IST activities also received financial support from “Fundação para a Ciência e Tecnologia” through project UID/FIS/50010/2013. The views and opinions expressed herein do not necessarily reflect those of the European Commission.