Relation between Energetic and standard Geodesic Acoustic Modes

J.-B. Girardo[1], D. Zarzoso[2], R. Dumont[1], X. Garbet[1], Y. Sarazin[1], S. Sharapov[3]

[1] CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France.

[2] Max-Planck Institut für Plasmaphysik, 85748 Garching, Germany.

[3] CCFE, Culham Science Centre, Abingdon, OX14 3DB, UK.

Turbulent transport in tokamaks is a major hurdle on the road to burning plasma, as it involves high losses of energy from the core of the reactors. Geodesic Acoustic Modes [1] (GAMs) are electrostatic, axisymmetric modes which are known to have interactions with turbulence [2]. In thermal plasma, those modes are damped. They can be non-linearly excited by turbulence, but they are then impossible to control.

GAM-like modes can be linearly excited by fast particles: they are then called Energetic-particle-driven GAMs (EGAMs). Those EGAMs were experimentally detected in JET [3] and DIII-D [4], and numerically found in the gyrokinetic codes GYSELA [5] and NEMORB [6]. In DIII-D and GYSELA, the EGAM frequency was found to be about 50% lower than the expected GAM frequency. On the one hand, due to their similarity with GAMs, the EGAMs are good candidates for reducing turbulent transport, thanks to vortex shearing. On the other hand, recent numerical simulations suggest that the impact of EGAMs on turbulence may not always be as positive as expected, and requires further investigation [7].

The relation between GAMs and EGAMs is somewhat unclear and remains to be explained. Through a linear, analytical model [8], the relation between GAMs and EGAMs is investigated. The fast particles are modelled by a Maxwellian bump-on-tail distribution function, in which only deeply passing ions are retained. The link between GAMs and EGAMs is found to depend on several parameters: the safety factor q, the fast ion parallel velocity $\bar{u}_{\parallel}$ normalised to the thermal velocity, the ratio τ_k of the fast ion distribution width to the bulk ion temperature, the ratio T_t/T_e of the bulk ion temperature to the electron temperature, the mass m_k and the charge number Z_k of the fast ions. Those parameters are explored in the following ranges: $1 \leq q \leq 3$; $2 \leq \bar{u}_{\parallel} \leq 4$; $0.1 \leq \tau_k \leq 2$ and $0.5 \leq T_t/T_e \leq 2$; while the masses and charge numbers correspond to those of Hydrogen, Deuterium, Tritium and Helium 3. For low values of q and m_k; for high values of $\bar{u}_{\parallel}$, τ_k and T_t/T_e, the EGAM originates from the GAM. On the contrary, for high values of q and m_k; for low values of $\bar{u}_{\parallel}$, τ_k and T_t/T_e, the GAM is not the mode which becomes unstable when fast particles are added: the EGAM then originates from a distinct mode, which is strongly damped in the absence of fast particles. Depending on the parameters, the resonance between the EGAM and the fast particles occurs at different frequencies. It turns out that the mode which, in the absence of fast particles, has a real frequency close to the resonance frequency will be the one to be excited when fast particles are added.

Last but not least, the experimentally and numerically observed ratio between the EGAM and the GAM frequencies, of the order of 1/2, is recovered with the present analytical calculation.

[1] N. Winsor et al., *Physics of Fluids* **11**, 11 (1968)
[2] K. Hallatschek et al., *Physical Review Letters*, **86**, 1223-1226 (2001)
[3] H. L. Berk et al., *Nuclear Fusion* **46**, S888-S897 (2006)
[4] R. Nazikian et al., *Physical Review Letters* **101**, 185001 (2008)
[5] D. Zarzoso et al., *Physics of Plasmas* **19**, 022102 (2012)
[6] A. Biancalani et al., To appear in *Nuclear Fusion* (2014)
[7] D. Zarzoso et al., *Physical Review Letters* **110**, 125002 (2013)
[8] J.-B. Girardo et al., Submitted to *Physics of Plasmas* (2014)