Self-generated oscillations in a magnetic island

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Multi-scale interaction dynamics in magnetic fusion plasmas over diverse spatiotemporal scales has been one of the recently emerging topics, as it is an interesting fundamental physics topic and at the same time a crucial physics issue to achieve sustainable high-performance operation of fusion devices. Especially, the multi-scale interactions among the microturbulence, the macroscale magnetic island and the self-generated mesoscale shear flow are getting high attention to be deeply understood [1] to minimize negative influences of magnetic island and to search for new paths to enhanced performance regimes with it [2]. A stimulating example is the recent achievement of internal transport barrier formation by locked mode in J-TEXT tokamak [3].

Self-generation of mesoscale ExB flows streaming on the magnetic surfaces [4,5] has widely been considered to trigger the transport barrier formation [6]. Around a magnetic island, the vortex flow streaming on the island contours can be self-generated from the microturbulence [7-9]. Once generated, it then undergoes two-time scale collisionless damping processes by toroidicity-induced linear couplings to the sidebands [10], namely GAM (geodesic acoustic mode) and the island-induced GAM [11] (which we call IGAM) [12].

The couplings of the vortex flow to GAM and IGAM, having their own characteristic frequencies, lead to the appearance of low-frequency oscillations in the vicinity near the magnetic island. Therefore, the oscillations can be regarded as a symptom of multi-scale interactions in the island region and thus used to detect them [12].

We present analytic theoretical derivation of the linear dispersion relation of the IGAM, together with that of the conventional GAM, using gyrokinetics following our previous works on the vortex flow evolution [13,14]. We have found that the eigenfrequency of the IGAM well inside a magnetic island is, in the long-wavelength limit,

$$\omega \sim \left(\frac{\sqrt{\epsilon}}{\hat{s}}\right)^{1/2} \bar{k}_{\parallel} v_{Ti},$$

where $\bar{k}_{\parallel} = kw/2L_s$ represents parallel variation of the IGAM along the magnetic island contour. Here, k and w are the helical wavenumber and the half-width of the magnetic island, and $L_s = qR/\hat{s}$ is the magnetic shear length. We predict this IGAM frequency would decrease toward the island separatrix monotonically.

Considering the physical origin of this IGAM, for its presence there should be turbulence inside the magnetic island, where the local linear turbulence drive is absent due to the flattened profiles. Therefore, detection of the IGAM activity inside magnetic island demonstrates the presence of significant turbulence spreading from outside into the island followed by vortex flow self-generation, which belongs to the self-consistent non-local turbulence dynamics [15].

References

[1] A. Ishizawa *et al*, *Plasma Phys. Control. Fusion* **61** 054006 (2019)
[2] K. Ida *et al*, *Phys. Plasmas* **11**, 2551 (2004)
[3] Feiyue Mao *et al*, *Nucl. Fusion* **65**, 066018 (2025)
[4] Z. Lin *et al*., *Science* **281**, 1835 (1998)
[5] P.H. Diamond *et al*., *Plasma Phys. Control. Fusion* **47**, R35 (2005)
[6] K.H. Burrell, *Phys. Plasmas* **27**, 060501 (2020)
[7] T.S. Hahm *et al*., *Phys. Plasmas* **28**, 022302 (2021)
[8] M. Leconte and Y.W. Cho, *Nucl. Fusion* **63**, 034002 (2023)
[9] T.S. Hahm and G.J. Choi, *Rev. Mod. Plasma Phys.* **8**, 30 (2024)
[10] G.J. Choi and T.S. Hahm, *Phys. Rev. Lett.* **128**, 225001 (2022)
[11] W.A. Hornsby *et al*., *Phys. Plasmas* **19**, 032308 (2012)
[12] G.J. Choi, *Phys. Plasmas* **31**, 042304 (2024)
[13] G.J. Choi, *Nucl. Fusion* **63**, 066032 (2023)
[14] G.J. Choi, *Rev. Mod. Plasma Phys.* **8**, 11 (2024)
[15] E.S. Yoon *et al*, *Nucl. Fusion* **64**, 126050 (2024)