Staircase Formation by Resonant and Non-resonant Transport of Potential Vorticity

Qinghao Yan[1], Patrick H. Diamond[2],
[1] Center for Fusion Sciences, Southwestern Institute of Physics, Chengdu, PRC
[2] Center for Astrophysics and Space Sciences (CASS) and Department of Physics, University of California San Diego, USA
qinghaoyan@outlook.com

The $E \times B$ staircase is a quasi-periodic pattern of pressure profile corrugations[1]. In this work, we present a new mechanism for $E \times B$ staircase formation, that involves resonant transport verses non-resonant transport. We start from a potential vorticity evolution system[2], which is derived from the Darmet model[3], and use quasi-linear theory, a model dispersion relation, and a bi-Lorentzian spectrum approximation, to construct the relation between the fluxes and the profiles. With these fluxes, we close the profile evolution equations and the extended turbulence intensity evolution equation, which together constitute a turbulence-profile evolution system. In this system, the Doppler effect from the $E \times B$ mean flow can cause resonance between trapped ion precession motion and the trapped ion mode, which drives a resonant transport contribution to the fluxes. The profiles will be flattened where the resonant transport is switched on. In contrast, for the regions of non-resonant transport, profiles are steeper. A quasi-periodic pattern of profile corrugation (the $E \times B$ staircase) spontaneously emerges in this system, which is the two states mentioned above, arranged as alternating layers in space, as shown in Figure 1.

We analyzed this staircase profile system and obtain the following results:

1. The feedback processes during the staircase pattern formation are identified.
2. An estimate of the critical value of the boundary heat flux is obtained, above which the staircase formation will be triggered.
3. An estimate scaling of the step size in the staircase pattern is obtained.

The resonant turbulent transport is also a mechanism for collisionless saturation of zonal flow[4]. This work is related to ITB and may suggest some new scenarios, like an enhanced confined L mode. Since the potential vorticity conserving system in this work is based on the trapped ion mode, there is also the possibility of further generalization to the problems of energetic particles and turbulence interactions.

This work is supported by National Key R&D Program of China under 2018YFE0303100, and the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences under Award Number DE-FG02- 04ER54738.

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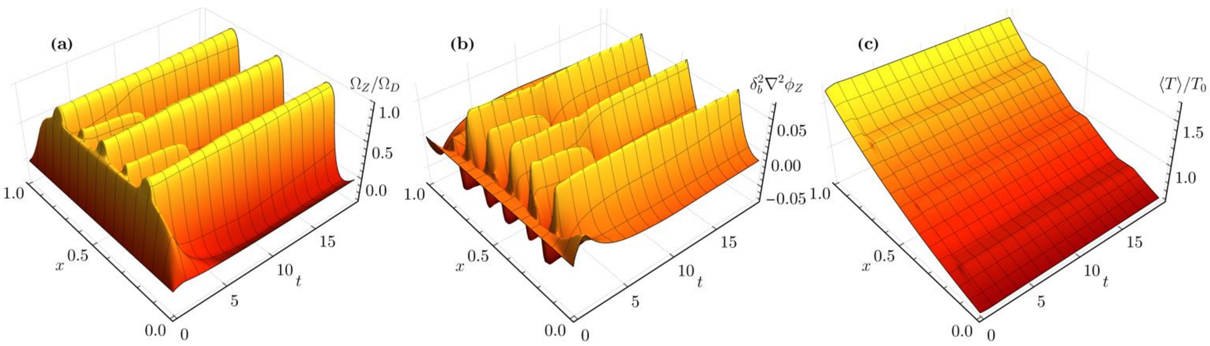

Figure 1. Evolution of profiles. (a) E × B mean flow evolve a quasi-periodic structure in space. (b) Flow shear or mean vorticity profile evolution. (c) Temperature profile evolve a quasi-periodic staircase-like structure.