Zonostrophic Instability and the Onset of the Dimits Shift

The onset of the Dimits shift in a simple nonlinear model of the toroidal ion-temperature-gradient-driven (ITG) instability is calculated in terms of a zonostrophic instability driven by discrete particle noise.

The Science

The numerical simulations of ITG turbulence by Dimits et al. [1] showed that heat flux does not turn on precisely at the linear instability threshold κ_{lin} as a function of temperature gradient κ, but only at a larger value κ_*. The distance $\kappa_* - \kappa_{\text{lin}}$ is called the Dimits shift. In general terms, it has been understood that the Dimits shift is caused by the excitation of zonal flows [1,2].

In the present work, the physics of the onset of the Dimits shift is examined in detail. It is shown that the transition is due to a zonostrophic instability. That instability is of contemporary interest in the context of geophysics and planetary atmospheres [3]; in plasma physics, it has previously been calculated for a generalized Hasegawa–Mima model [4]. In all of that research, it was assumed that the instability was of a homogeneous turbulent state; however, below linear threshold there is no turbulence. Instead, we argue that the instability is driven by discrete particle noise. Using a stochastic model, we calculate the neutral curve for the onset of wave number q (see the figure). Details can be found in Ref. 6.

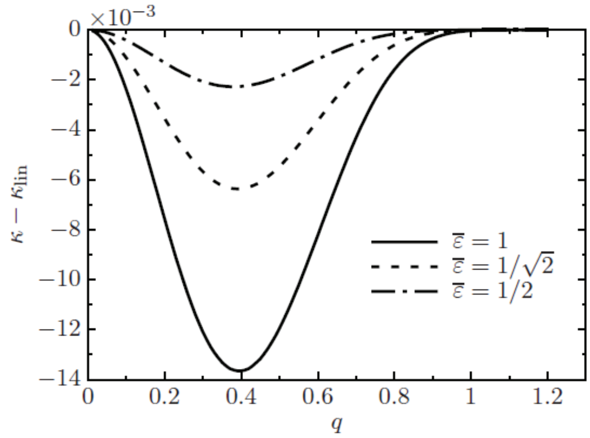

Fig. 1. Representative neutral curves for the distance $\kappa - \kappa_{\text{lin}}$ from linear threshold as a function of zonal wave number q (dimensionless units). For details, see Ref. 6.

The Impact

This new insight updates an important 50-year-old paradigm of Kadomtsev [5] for the transition to turbulence, which did not include zonal flows, to encompass zonostrophic instability. It provides a solid theoretical foundation for moving forward to the next challenge, namely the calculation of the right-hand boundary κ_* of the Dimits shift.

References

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