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Key impact of phase dynamics and diamagnetic drive on Reynolds stress in magnetic fusion plasmas

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Reynolds stress is a key facet of turbulence self-organization. In the magnetized plasmas of controlled fusion devices, the zonal flows that are primarily driven by the averaged Reynolds stress modify the confinement performance. Understanding its dynamics is therefore crucial in view of predicting the turbulence level and the associated transport.

We address this problem with full-f simulations of ion temperature gradient-driven turbulence with the 5-dimensional gyrokinetic GYSELA code [1], complemented by 1-dimensional nonlinear simulations of a minimal model for interchange turbulence [2].

From the detailed analysis of the three-dimensional electric potential and transverse pressure fields, we show that the diamagnetic contribution to the Reynolds stress – stemming from finite Larmor radius effects – exceeds the electrostatic contribution by a factor of about two (Figure (a)). Both contributions are in phase such that they add up, indicating that pressure does not behave as a passive scalar [3].

In addition, the Reynolds stress induced by the electric drift velocity is found to be mainly governed by the gradient of the phase of the electric potential modes rather than by their magnitude (Figure (b)). By decoupling Reynolds stress drive and turbulence intensity, this property indicates that a careful analysis of phase dynamics is crucial in the interpretation of experiments and simulations [3].

References:

[1] V. Grandgirard et al., Comput. Phys. Commun. 207 (2016) 35–68
[2] N. Bian et al., Phys. Plasmas 10 (2003) 1382
[3] Y. Sarazin et al., Plasma Phys. Control. Fusion 63 (2021) 064007; https://doi.org/10.1088/1361-6587/abf673

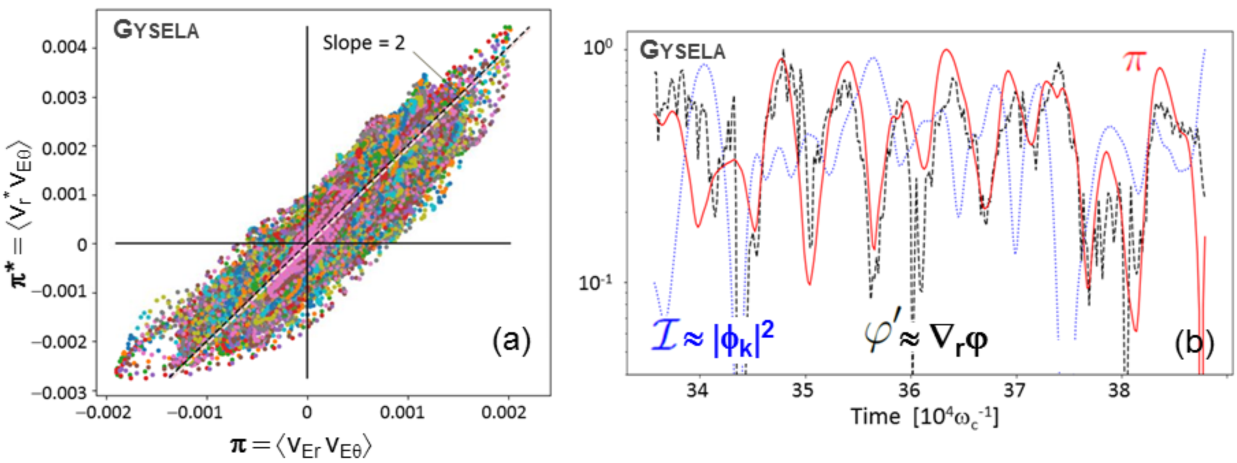

Figure: Zonal Flows V_{ZF} are governed by the divergence of the Reynolds stress: $\partial_t V_{ZF} + \nabla_r (\pi+\pi^*) = $ r.h.s.
(a) The diamagnetic Reynolds stress π^* is in phase with and about 2 times larger than the Reynolds stress π (each point corresponds to a value at a given time t and location r).
(b) The dynamics of the Reynolds tress $\pi \approx \Sigma\, |\phi_k|^2\, \nabla_r \varphi$ is mostly governed by the phase gradient $\nabla_r \varphi$ rather than by the turbulence intensity $|\phi_k|^2$