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Dependence of turbulent transport on GAMs

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Introduction

Different from the zonal flows in the tokamak core, which are the only mechanism for turbulence saturation there, geodesic acoustic modes (GAM) in the edge are only one possibility for turbulence control in their regime, considering the higher efficiency of nonlinear turbulence interactions in the edge. In fact, experimental observations of GAMs so far seem to be limited to rather weak activity with displacement amplitudes of $\lesssim$ 1cm [1, 2], which are unlikely to seriously influence the turbulence amplitudes as, e.g., in the turbulence simulations for the transitional regime in [3]. One difference is of course the simplistic circular geometry used in those simulations, whence in the first part below it is explored in how far flux surface ellipticity modifies GAM activity and its impact on the turbulence. Studying the effect of the experimentally uncertain background gradients on the GAM activity, it was found that in particular very high gradients can cause rather strong GAMs with a substantial impact on the transport.

The numerical turbulence studies were performed with the NLET code [4] using two-fluid electrostatic Braginskii equations with modified parallel heat conduction coefficient implementing a collisionless heat flux limit. The magnetic geometry was represented by local Miller-equilibria [5].

Ellipticity

When simply using the experimental flux surface shape in turbulence simulations it is quite hard to separate the geometry effect on the turbulence itself from the one on the GAMs, while on the other hand experimentally neither the magnetic geometry nor the gradients in the plasma are sufficiently accurately known to determine the correct turbulence regime. Changing the magnetic geometry of computer turbulence studies in a straightforward manner thus usually results in qualitatively different types of turbulence for the different geometries, which cannot be compared with each other. Empirically it turns out that fixing the ratio of gradient lengths, magnetic curvature radii and the local shear length at the outboard midplane results in quite comparable scenarios.

Fig. 1 shows GAM flow-patterns for $\kappa = 0.5, 1, 1.7$ and concomittant $s_\kappa \equiv \mathrm{d}\ln\kappa/\mathrm{d}\ln\mathrm{r} = -0.5, 0, 0.7$, respectively, with ratio of connection length to local shear length at the outboard midplane $L_c/L_s = 2\pi$ corresponding to total shear $s = 1$ for circular concentric flux surfaces.

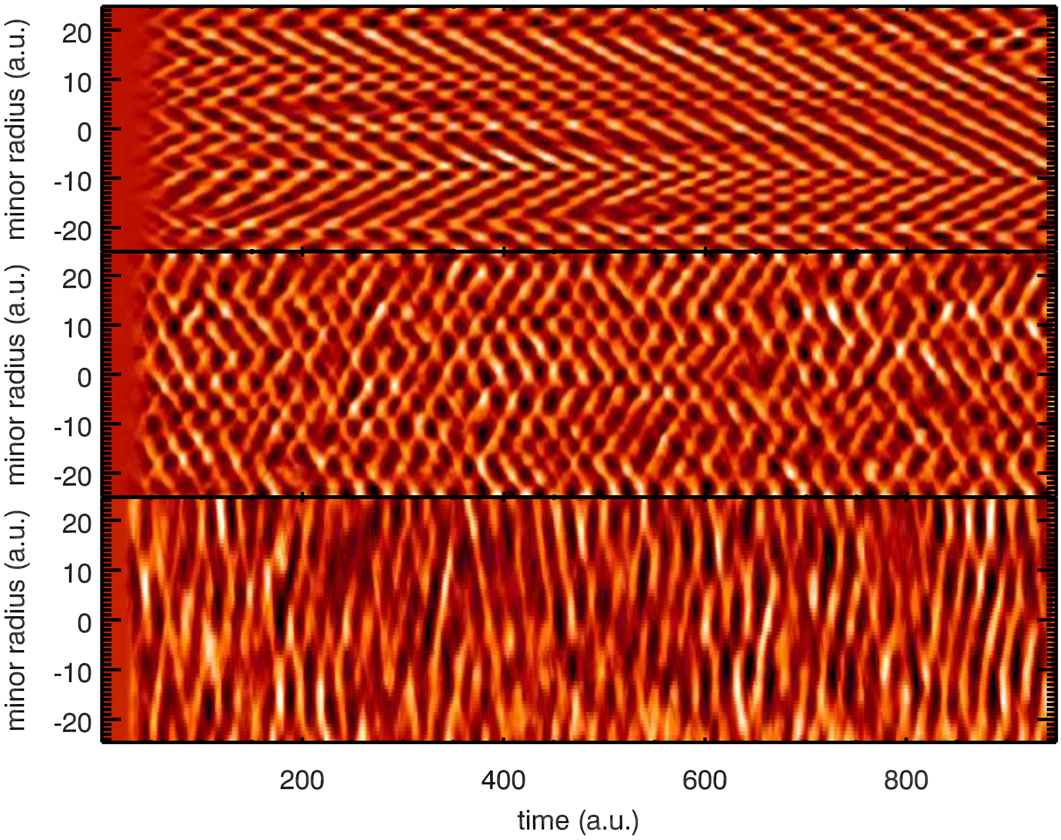

Figure 1: Color coded GAM poloidal flow velocity for $\kappa = 1.7$ (top), $\kappa = 1$ (middle), $\kappa = 0.5$; note the different scale lengths and frequencies.

The total shear $\mathrm{d}\ln q/\mathrm{d}\ln r$ (r is the Miller radius) was $0.47, 1.00, 2.95$, respectively. The other parameters were taken to be identical as in [3]. Apart from the change in frequency, which follows the linear predicitions, the flow patterns are qualitatively identical. The turbulent heat fluxes are, respectively, $\chi(\rho_s^2 c_s/R) = 10, 1.0, 0.10$, while the RMS flow levels are $\langle|v_\theta|\rangle/v_{di,e} = 0.95, 1.64, 1.44$.

To clarify, whether the 10-fold transport reduction for each step of increasing ellipticity is in part to the GAM, the turbulence simulations for $\kappa = 1$ and 1.7 have been restarted, while artificially suppressing the flux surface averaged poloidal flows. This yielded the transport coefficients $\chi(\rho_s^2 c_s/R) = 10, 2.5$, which is an order of magnitude larger and also shows less favourable influence from the ellipticity than the runs with self-consistent GAMs.

High gradient regime

In the absence of diamagnetic velocities, such as for pure resistive ballooning turbulence, the diamagnetic drive [6] is completely switched off, whence for normal edge gradients GAM activity is suppressed [3]. However, for sufficiently high gradients, the GAMs return. Fig. 2

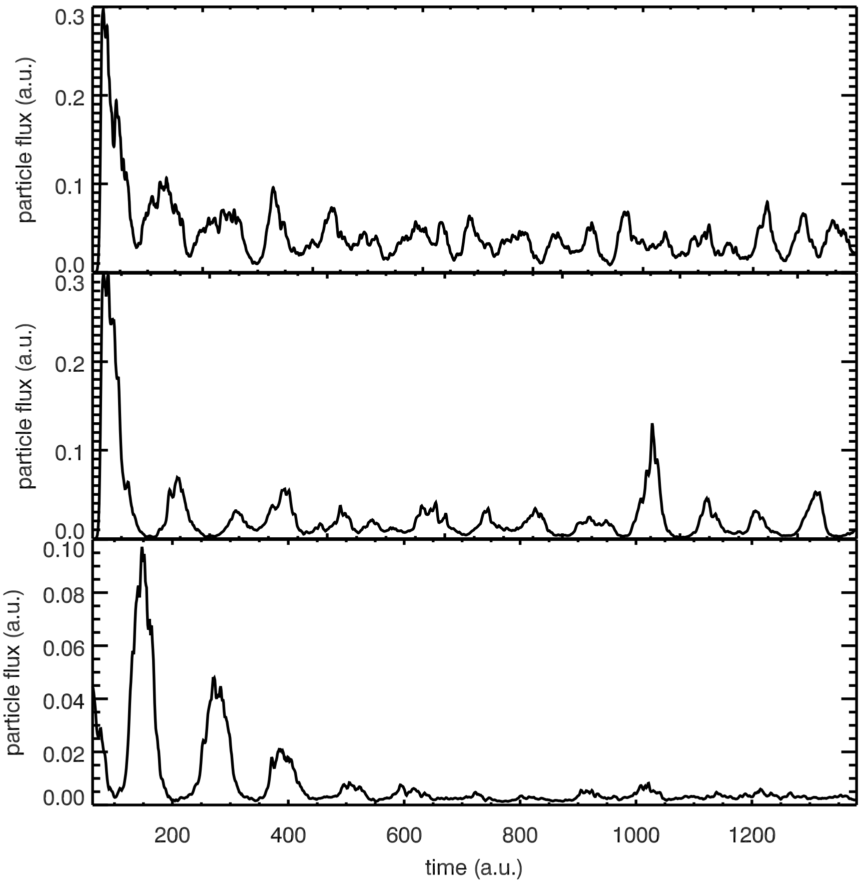

Figure 2: Time evolution of particle flux for isothermal resistive ballooning turbulence simulation with $L_p/R = 0.01$ (top), 0.0025 (middle), 0 (bottom) in the respective mixing length units. Particle flux becomes bursty and eventually dies out in the limit of large gradients.

shows the average particle flux as a function of time for varying gradients. Normalising the transport to the mixing length estimates (which would make its value constant without the GAMs) shows a marked decrease and a transition from continuous transport to bursts due to the GAM oscillations.

The reason for this change is the behavior of the ratio of turbulence kinetic energy E_ϕ to fluctuation free energy E_p. It can be estimated order-of-magnitudewise in the mixing-length framework as follows: During an eddy turn over time – one step in a random walk process for the pressure fluctuations – a percentage $\propto L_p/R$ (L_p is the pressure gradient length, R the curvature,i.e. major, radius) of the fluctuation free energy is converted into kinetic energy by expansion of the plasma in the inhomogeneous magnetic field, while the rest is dissipated into heat. Therefore,

$$\frac{E_\phi}{E_p} \sim \frac{v^2}{\delta p^2} \propto \frac{L_p}{R} \ll 1 \tag{1}$$

where δp and v are the typical pressure and velocity fluctuation amplitudes. For sufficiently large gradients $L_p \ll R$ and $v^2 \ll \delta p^2$, whence the Reynolds stress is negligible compared to the GAM drive by asymmetric anomalous transport [3] via the Stringer-Winsor force (SW). Since the average GAM amplitude is then in balance with the SW drive (and not the Reynolds stress), it is scaled up in comparison to the turbulence velocities for increasing gradients, eventually suppressing the turbulence.

In the limit $L_p/R \to 0$ a quasistationary flow patterns results, which completely suppresses the transport (in mixing length units).

Summary

Numerical turbulence studies pertaining to edge paramters show that turbulence driven GAMs can control the transport – reducing it by a an order of magnitude – in situations where either strong diamagnetic effects give rise to the diamagnetic GAM drive due to fluctuating background profiles, or the free energy of pressure fluctuations (and with it the Stringe-Winsor driven GAM fluctuations) is much larger than the turbulence kinetic energy, such as in the edge and potentially in transport barriers.

References

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