§29. Turbulent Plasma as a System Far from Thermodynamical Equilibrium

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Statistical theory for the strong plasma turbulence has been developed. The theory has provided an extended fluctuation dissipation theorem, probability density function of the fluctuation level, average spectrum of turbulence and turbulent transport. The transition between the various types of fluctuations has been found, and the phase diagram was given. The mini-max principle for strong turbulence was established. Transition probability between different turbulent states is obtained. These results formgeneralization of the principles in the classical systems near thermodynamical equilibrium; e.g., Kubo formula, Einstein's relation, Boltzmann's law, Prigogine's principle, Onsager's symmetry, Curie's principle, and Arrhenius law. The result of strong plasma turbulence is summarized, showing that the plasma theory has extended the statistical physics of far non-equilibrium systems.

References

[1] S.-I. Itoh and K. Itoh: J. Phys. Soc. Jpn. **68** (1999) 1891; 2611; **69** (2000) 408; 427; 3253.
[2] A. Yoshizawa, S.-I. Itoh, K. Itoh, N. Yokoi: Plasma Phys. Control. Fusion **43** (2001) R1

	Near Thermodynamical Equilibrium	**Far-non-equilibrium**
Basic assumption	Stosszahl Ansatz; $1/\Omega$ -expansion	Large number of degrees of freedom with positive Lyapunov exponents
Damping	Molecular viscosity $\gamma_c = \mu_c k_\perp^2$	Nonlinear (eddy) damping$\gamma_N \sim \tilde{\phi} k_\perp^2 / B$
Micro vs Macro	$\mu_{\mathrm{micro}} = \mu_{\mathrm{macro}}$:Onsager's Ansatz	Scale-dependent
Excitation		
(random)	Thermal excitation	Nonlinear drive
(coherent)	(none)	Instability drive
Decorrelation rate	γ_c	Nonlinear decorrelation λ_1
Balance	FD Theorem Einstein's relation	Extended FD Theorem $I \sim \frac{nonlinear\,noise}{nonlinear\,decorrelation}$
Partition	Equipartition $E_k \sim T\,k$	Nonlinear Balance $E_k \sim \left\lvert \nabla p_0 \right\rvert k^{-3}$
Probability density function	Boltzmann $P(\mathcal{E}) \sim \exp\left(- \mathcal{E}/k_B T\right)$	Integral of renorm. dissipation $P(\mathcal{E}) \sim \exp\left(- S(\mathcal{E})\right)/g$: power-law tail
Min./Max. principle	Maximum entropy/ Min. entropy-production rate	$S(\mathcal{E})$ minimum
Phase boundary	Maxwell's construction	$S(\mathcal{E}_A) = S(\mathcal{E}_B)$
Transition probability	$\ln(K) \sim -\Delta Q/T$:Arrhenius law	$K \propto \exp\left(- S(\mathcal{E}_{\mathrm{saddle}})\right)$: power law
Transport matrix	Onsager's symmetry	Not necessarily symmetric
Interference of fluxes	Curie's principle	interferences between heat, particle, and momentum
Transport coefficients	independent of gradient	depend on gradient