S5-3

Ion Temperature Gradient Driven Turbulence with Strong Precession Resonance
強い捕捉イオン共鳴を伴うイオン温度勾配乱流

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As a typical example of plasmas in non-equilibrium and extreme state, turbulent plasmas with strong resonance are introduced. Two examples are discussed. The first one is current carrying 1d plasmas. The role of phase space structures in driving nonlinear ion acoustic turbulence is illustrated by rigorous numerical investigation. The second example is ion temperature gradient driven turbulence with strong precession resonance. The role of clusters of resonant trapped ions, called trapped ion granulations is emphasized throughout. Impact of trapped ion granulations on transport and frequency broadening is discussed.

1. Introduction

Turbulent plasma is an example of a system in non-equilibrium and extreme state. Since turbulent plasmas of interest, such as space plasmas, fusion plasmas, etc. are often in collisionless regime, the dynamics of turbulent plasma involves the degree of freedom in phase space (velocity + real space). This is very unique feature of turbulent plasmas. As a consequence, waves are Landau-damped even in collisionless plasmas, where wave-particle resonance allows energy exchange between them. When resonance becomes strong enough to trap resonant particles in waves, phase space vortex (BGK modes) can form. Once formed, phase space vortex can drive turbulent transport by exerting dynamical friction, as first predicted by Dupree.[1]

In this work, we discuss recent developments in the research of turbulent plasmas with strong wave-particle resonance. In the first part of the work, we discuss recent numerical study of current carrying plasmas.[2] The role of phase space vortex in driving nonlinear current driven ion acoustic turbulence is emphasized. In the second part, we discuss application to fusion plasmas. As a specific example, we focus on ion temperature gradient driven turbulence with strong precession resonance.[3,4] We discuss that clusters of resonant trapped ions, called trapped ion granulations, can form and impact turbulence characteristics and transport.

2. Current Carrying Plasma

Here we consider a current carrying 1d plasma. The system is linearly unstable, when electron drift velocity exceeds ion acoustic speed. This is a well known current driven ion acoustic (CDIA) instability and is a typical example of plasma instability with velocity space origin.

When resonance becomes strong enough, phase space density holes can form. For example, formation of ion holes and its impact on subcritical instability was studied theoretically and numerically. More recently, rigorous numerical simulation was used to illustrate structures in phase space and to identify the role of phase space structures in nonlinear instability. In contrast to previous study, the recent work unambiguously identifies nonlinear instability in barely unstable regime.[2]

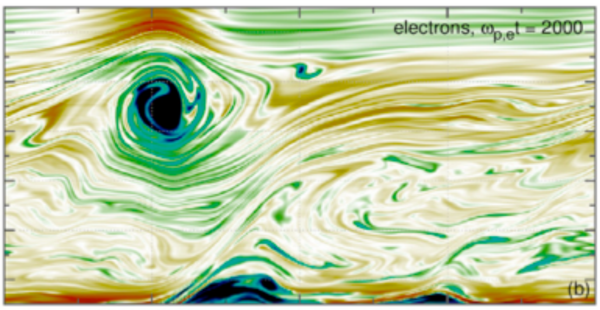

Fig.1. Illustration of phase space vortex in electron distribution function. Abscissa space, ordinate velocity.[2]

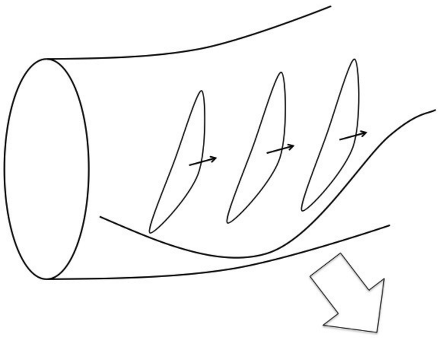

Fig. 2. A cartoon of trapped ion granulations and transport via dynamical friction.[4]

3. Magnetically confined plasma

Strongly resonant turbulence can arise in fusion plasmas as well. In tokamaks, magnetically trapped particles are characterized by 1D precession motion. Thus precession resonance between trapped particles and modes has 1D structure and can have strong resonance. As a result, in trapped ion turbulence, formation of clusters of resonating trapped ions (trapped ion granulations) is quite likely.[3] Once formed, trapped ion granulations release free energy, by exerting dynamical friction on electrons. Dissipative electrons are required to trigger free energy release from this channel.

Another macroscopic consequence due to the formation of trapped ion granulations is broadened spectrum.[4] Of course in turbulent plasmas frequency spectrum is broadened. However, in addition to conventional broadening due to mode-mode coupling, granulations can broadens the frequency spectrum via Cerenkov emission. While trapped ion granulations move through plasmas, they emit waves via Cerenkov emission. Since the Cerenkov emitted waves do not have to satisfy dispersion relation, spectrum is broadened. The line width is calculated in [4] and shows sensitivity to electron dissipation. This is since trapped ion granulations release free energy via dynamical friction.

As on-going work, we are working on numerical identification of trapped ion granulations. In this direction, we are trying to calculate microscopic property of trapped ion granulations, i.e. strong correlation at small scales. 2 point phase space density correlation of trapped ion granulations show logarithmic divergence in the limit of $1 \to 2$. For typical parameters, required resolution is very severe. For example, required resolution to resolve the distance of one resonance to another at typical wave number is $\Delta E / T_i \sim 0.04$ for $q = 2$ and $\rho_* = 1/200$. It is very demanding to resolve this scale while resolving spatial turbulence scales. For this reason, reduced model would be more appropriate for this study, than complete full gyrokinetic models.

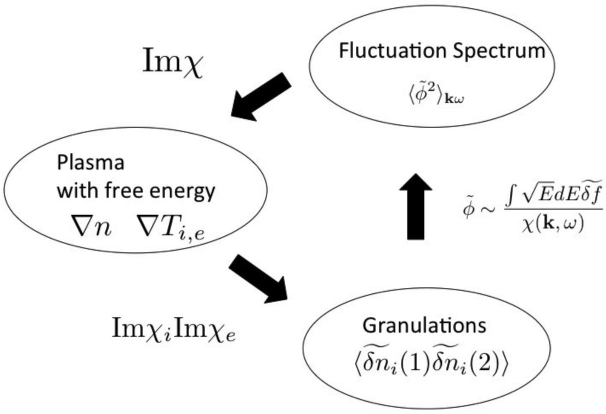

Fig. 3. Schematics for steady state balance.[4]

4. Summary and discussion

In summary, we discussed strongly resonant turbulence as a typical example of non-equilibrium and far-extreme state. In 1d current carrying plasmas, phase space density holes due to electrostatic trapping can drive nonlinear instability. In toroidal plasmas, trapped ions can resonate with waves and can form clusters of resonating trapped ions, granulations. Once formed, trapped ion granulations drive transport by exerting dynmiacal friction on electrons and broadens frequency spectrum by Cerenkov emitting attached wake. Numerical investigation is on-going to identify trapped ion granulations.

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