Drift breathers in magnetized plasmas

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1 Introduction

Nonlinear wave is an important subject both in mathematic and physics. In particular, nonlinear waves often appear in the context of continuous medium, such as fluids and plasmas. In plasmas, various nonlinear waves are excited. A classic example is a soliton, where nonlinearity and dispersiveness determine the nature of waves. Another example is a breather[1, 2], which introduces transient nonlinear response of plasmas. Although breathers were originally studied in the context of mathematical interest, they attracted attention once their relation to freak waves in ocean has been pointed out. Its excitation is confirmed in water tank experiments[3], and then in various other systems such as optical fibers, plasmas[4], etc. In this work, we discuss the excitation of breathers in the context of magnetized plasmas. Taking drift waves as a prototypical wave in fusion plasmas, we show that drift waves can nonlinearly evolve into breathers[5, 6]. This is shown both from theory and experiments. The excitation of drift breathers has various implications on magnetically confined fusion plasmas. We argue that drift breathers can transiently increase particle flux in fusion plasmas, which may be useful to pump out impurities from the system[7]. An extension of the theory to drift-Alfven wave is ongoing, which may shed a light in understanding abrupt excitation of electromagnetic bursts in plasmas.

2 Description of nonlinear breathers in magnetized plasmas

2.1 Formulation: From linear to nonlinear evolution of drift waves

Here we introduce a model to describe the nonlinear evolution of drift wave turbulence in magnetized plasmas. Consider a cylindrical plasma with a constant magnetic field applied in the axial (z) direction (Fig.1). The plasma column is pinched by the magnetic field, and the density gradient naturally builds up in the radial direction (r). For simplicity, the plasma is assumed to be uniform in the axial and azimuthal directions (θ). Assuming further that the electron temperature T_e is constant and the ions are cold, the nonlinear evolution of fluctuation is described by the Hasegawa-Mima (HM) equation[8],

$$\partial_t(1-\rho_s^2\nabla_\perp^2)\frac{e\phi}{T_e}+v_*\partial_y\frac{e\phi}{T_e}+\frac{c}{B}\hat{z}\times\nabla_\perp\phi\cdot\nabla_\perp(1-\rho_s^2\nabla_\perp^2)\frac{e\phi}{T_e}=0. \tag{1}$$

Here ρ_s is the ion sound Larmor radius, $\perp$ denotes the direction perpendicular to the magnetic field, i.e. $\nabla_\perp=(\partial_r, r^{-1}\partial_\theta)$. The parameters are: e, the electric charge; ϕ, the electrostatic potential; v_*, the drift velocity; and c, the speed of light. Correspondence between (r,θ) and (x,y) will be assumed hereafter. The HM equation is the simplest model for describing the nonlinear dynamics of fluctuations in magnetized plasmas, and it captures several interesting features of plasma turbulence[9].

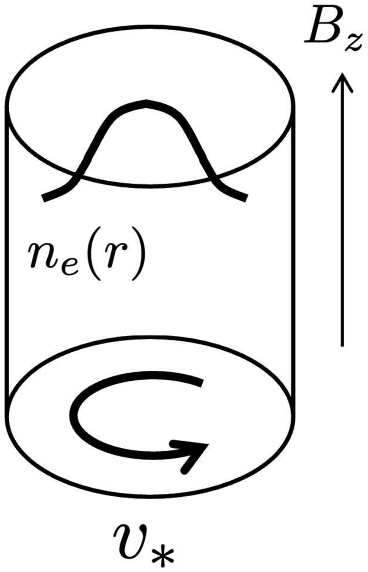

Fig. 1: A plasma of interest. Magnetic field is imposed in the axial direction. Plasma has inhomogeneity in the radial direction. For simplicity, only density field is considered. The density gradient drives drift waves, which propagate in the azimuthal direction at the drift speed v_*.

As is evident from Eq.(1), a key ingredient in the dynamics is a collective mode known as the drift wave. Its dispersion relation is obtained by linearizing Eq.(1) and performing Fourier analysis, yielding

$$\omega=\frac{v_*k_y}{1+\rho_s^2k_\perp^2}. \tag{2}$$

In the long wavelength limit, drift waves propagate primarily in the azimuthal direction. Its speed is given by the drift velocity $v_*\propto\nabla n$. Drift waves are dispersive, as indicated by the denominator. Since the dispersion relation has a form similar to that of Rossby waves in planetary atmospheres, the physics of magnetized plasmas shares many similarities with that of rapidly rotating atmospheres.

Nonlinear evolution of drift waves is of interest and its dynamics is formulate here. It is well known that drift waves nonlinearly interact to drive large scale flows such as zonal flows and streamers. Typical situation is depicted in Fig.2. Once generated, these flows feed back onto the original drift waves through shear. This results in a coupled nonlinear evolution of drift waves and flows. The nonlinear dynamics can be formulated using modulational analysis. In this framework, the fluctuating potential is written as $\phi = Re(\psi(\mathbf{X}, \tau)e^{i\mathbf{k}\cdot\mathbf{x}-i\omega t})$. Here the fast variation associated with drift waves is contained in the carrier phase. The wave amplitude field (or envelope) is allowed to vary slowly both in time and space. The slow dependence is denoted by $\mathbf{X}$ and τ. By applying a reductive perturbation expansion[10, 11, 12, 5], we have the coupled evolution as

$$\left(i\partial_\tau + \frac{1}{2}\frac{\partial^2\omega}{\partial k_m \partial k_n}\partial_m\partial_n\right)\psi = \mathcal{N}(\psi, \bar{\Psi}, ...), \tag{3a}$$

$$(\epsilon\partial_\tau - \mathbf{v}_g \cdot \nabla)\nabla_\perp^2 \bar{\Psi} = 2\rho_s^2\omega_{ci}[k_x k_y(\partial_X^2 - \partial_Y^2) + (k_y^2 - k_x^2)\partial_{XY}]|\psi|^2, \tag{3b}$$

$$(\epsilon\partial_\tau - \mathbf{v}_g \cdot \nabla)\bar{N} + v_*\partial_Y \bar{N} = 0. \tag{3c}$$

Here $\bar{\Psi}$ is large scale flow field, $\bar{N}$ is modulated density field, ϵ is the expansion parameter, $\mathbf{v}_g = \partial\omega/\partial\mathbf{k}$ is the group velocity. The repeated indexes, m and n, are summed over x and y. The nonlinear term $\mathcal{N}$ originates from the nonlinear term in Eq.(1), and its specific form is

$$\mathcal{N} = c_s\rho_s\hat{z} \times \nabla\bar{\Psi} \cdot \mathbf{k}\psi + \frac{1}{1+\rho_s^2 k_\perp^2}\hat{z} \times \mathbf{k} \cdot \nabla\bar{N}. \tag{3d}$$

Equations (3a), (3b), and (3c) describe the coupled dynamics of drift waves and large scale flows and fields.

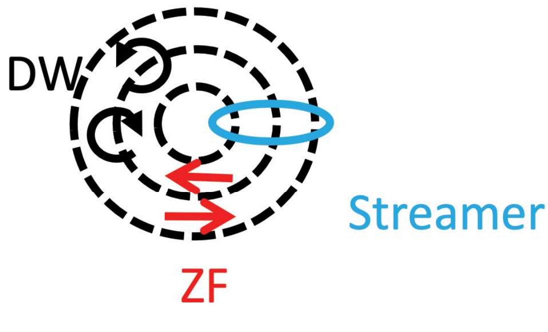

Fig. 2: The cross section of a cylindrical magnetized plasmas. Small scale drift wave turbulence nonlinearly interact with each other to pump large scale flows, such as zonal flows or streamers. Zonal flows are purely azimuthal with the radial variation, while streamers are radially elongated and azimuthally localized.

2.2 Nonlinear Schrödinger equation for drift waves and flows

Althourgh Eqs (3a), (3b), and (3c) can be in principle solved to characterize the nonlinear evolution of drift waves and flows, a simpler and more tractable model can be derived by analyzing limiting cases. In particular, two limits can be considered for flow fields. One is the streamer limit, in which the large scale spatial modulation is anisotropic and satisfies $\partial_Y \gg \partial_X$. The opposite limit, $\partial_X \gg \partial_Y$, corresponding to the steeper radial modulation is associated with zonal flows. We can analyze the coupled dynamics by focusing on one flow. For example, consider the case of radially elongated streamers, where

$$V_X = (c/B)(\hat{z} \times \nabla\bar{\Psi})_X \propto -\partial_Y \bar{\Psi}. \tag{4}$$

In this case, the large scale field can be eliminated, yielding a single equation for the drift wave envelope:

$$i\partial_t \psi + \alpha \partial_y^2 \psi + \beta |\psi|^2 \psi = 0. \tag{5a}$$

Here, the standard notation for the spatial and temporal variables is restored with the understanding that they describe the envelope evolution. Equation (5a) is the well-known one dimensional nonlinear Schrödinger equation (1D NLS). Here the dispersion is set by

$$\alpha = \frac{1}{2}\frac{\partial^2 \omega}{\partial k_y^2} \tag{5b}$$

and the coefficient for the nonlinear term is

$$\beta = c_s k_x \frac{2\rho_s^2 k_x k_y c_x}{v_{gy}} \left(1 - \frac{v_{py}}{v_{gy}}\right). \tag{5c}$$

As discussed above, the nonlinear feedback is provided from the coupling to large scale flows. Loosely put, the nonlinear convection in HM equation is $\sim V_{x,str}\partial_x \phi$. Since $V_{x,str}$ is driven by Reynolds stress, $V_{x,str} \propto \langle \tilde{v}_x \tilde{v}_y \rangle \propto k_x k_y$. These dependences are clearly seen in the coefficient for the nonlinear term, β. Finally, we note that a similar equation can be derived for the case with zonal flows. This case is further elaborated later.

NLS appears in the many physical contexts. NLS for drift waves is one example of such wide varieties. In its original form, NLS is derived for the Bose-Einstein condensation of superfluids. Classical systems also provide relevant physical contexts. In particular, the nonlinear evolution of dispersive waves is amenable to the description based on NLS. Example includes, but not limited to, surface waves in the ocean, light propagating in nonlinear media, acoustic waves in complex plasmas, etc. Common ingredients are wave dispersion, nonlinear feedback, etc. In particular, freak waves are predicted to occur and observed in water tank experiments. Since then, freak waves are observed in each systems. Below, we show that freak waves can be also excited in the context of drift waves, which impact confinement of fusion plasmas.

2.3 Drift breathers

The nonlinear evolution of drift waves described by NLS (Eq.(5a)) is of interest here[5, 6]. First, note that Eq.(5a) admits a homogeneous solution, $\psi = A_0 \exp(i\beta A_0^2 t)$. This introduces a nonlinear frequency shift of underlying drift waves. Then we can analyze the evolution of spatially inhomogeneous perturbation. Initially, a spatially varying perturbation is imposed on the uniform wave field, and its evolution is analyzed. By performing a linear perturbation analysis, we obtain the dispersion relation:

$$\gamma_{mod}^2 = 2\alpha\beta q^2 A_0^2 - \alpha^2 q^4. \tag{6}$$

Here q is the wave number of the modulation field and γ_{mod} is the growth rate of the perturbation. Thus, wave dispersion has a stabilizing effect, whereas nonlinear coupling is destabilizing for modulation. Instability occurs when $\alpha\beta > 0$, and the nonlinear drive must overcome the stabilizing effect of wave dispersion. This competition defines the critical amplitude for the onset of modulational instability, as

$$A_0^2 > \frac{\alpha}{2\beta} q^2. \tag{7}$$

When this condition is satisfied, the initial modulation continues to grow. The wave energy condenses spatially, and an inhomogeneous wave field develops. This inhomogeneous wave state is effective in driving large scale flows, since they introduce finite Reynolds forcing. The modulational instability is often invoked to explain the generation of large scale flows from drift waves. There are attempts to regulate flow growth via the modulational instability.

While inhomogeneous wave field develops via modulational instability, this process does not proceed forever. Its nonlinear stage can be analyzed by solving NLS non-perturbatively. Indeed, the 1D NLS is well known for its exact solutions. Here, recalling that y serves as a proxy for the azimuthal angle of a cylindrical plasma, we seek for an exact solution with periodic boundary condition in y. In this case, we obtain Akhmediev breather solution as

$$\psi(y,t) = A_0 e^{i\beta A_0^2 t} \left(\frac{\sqrt{2}\nu^2 \cosh(\beta A_0^2 \sigma t) + i\sqrt{2}\sigma \sinh(\beta A_0^2 \sigma t)}{\sqrt{2}\cosh(\beta A_0^2 \sigma t) - \sqrt{2-\nu^2}\cos(Ky)} - 1 \right). \tag{8}$$

Here $\sigma = \nu\sqrt{2-\nu^2}$, $K = \nu\sqrt{\beta A_0^2/\alpha}$, and ν is a parameter. Typical wave field described by Eq.(8) is spatially periodic. Depending on the parameter ν, the solution may appear localized. Moreover, its time evolution is unique in that it is also localized in time. Thus, while the energy increases initially by modulational instability, the energy accumulated in space starts decreasing by radiation. The entire evolution leads to the transient behavior of the wave energy.

Note that the existence of Akmediev breather requires $\nu < \sqrt{2}$. This implies that

$$A_0^2 > \frac{\alpha}{2\beta} K^2. \tag{9}$$

This condition is effectively same as that for the onset of modulational instability, Eq.(7). Thus, it is natural that once modulational instability is triggered, the wave pattern develops nonlinearly into the form described by Eq.(8). This transient nonlinear evolution is a natural consequence of the dynamics described by the NLS with periodic boundary conditions. In the context of magnetized plasmas, the nonlinear evolution of the coupled system of drift waves and streamers exhibits transient behavior. The excitation of breathers, or freak waves, is an inevitable outcome of the nonlinear evolution of drift waves. We call this as drift breathers, and will elaborate consequences on experiments and magnetic confinement below.

The behavior of breathers is very visible in amplitude. Although this can be used to detect breathers in experimental data, a more stringent condition is desirable. In particular, turbulent plasmas exhibit several intermittent behaviors. Thus distinguishing the signal for breathers requires additional condition. For this, we argue that the evolution of the phase of the wave envelope can be helpful. This may be understood from the assumption behind deriving the exact solution. In order to obtain Eq.(8), the wave field is written as

$$\psi = A_0 \exp(i\beta A_0^2 t)(u + iv). \tag{10}$$

Here u, v are a real function. Then, it is assumed that

$$\frac{v}{u+1} = \frac{\sqrt{2-\nu^2}}{\nu} \tanh(\beta A_0^2 \sigma t) \tag{11}$$

which gives integrable form of Eq.(5a). Equation (11) constraints the time evolution of the wave field u and v. Since the relative relation of u and v sets the phase of the complex wave amplitude, this is equivalent to the constraint on the phase evolution of the wave field. Indeed, by taking $t \to \pm\infty$, we have

$$\psi(y,t) \to A_0 e^{i\beta A_0^2 t}(\nu^2 - 1 \mp i\sigma) \tag{12}$$

So the phase is modulated and differs at $t \to \pm\infty$. By comparing the wave field at $t \to \pm\infty$, we can identify whether breathers are excited or not. The phase modulation, in addition to the amplitude modulation, can be used to detect breather excitation in experimental data.

The excitation of transient breathers in magnetized plasmas was searched for in actual experimental data. The data were obtained from linear magnetized plasma experiment, PANTA[5]. In PANTA, plasma is produced by the helicon source. The source is located in one side of the device and plasma is generated by injecting Ar. Then plasmas flow along the magnetic field, which is typically 900 gauss. The size of the plasma is 2-3 meters in the axial direction, and the radius is about 10 cm. The data is obtained from a probe array, with multiple measurement points in the azimuthal direction. The probe data provide a spatio-temporal pattern, and the footprint of the breather excitation can be extracted by using the theoretical wave form described above. We started by comparing the spatial wave form. By calculating the correlation between the theoretical wave form and experimental data provided by the multi-point measurements, we can record the time where a similar spatial pattern is detected. Each event can be averaged within a typical temporal window, yielding the averaged temporal evolution of the wave amplitude and phase. The results show a good agreement, and we conclude that the excitation of breathers in the context of drift waves is very likely. Finally, we note that breathers are excited only under limited experimental conditions. In particular, it appears that specific conditions must be satisfied for the excitation of drift breathers. For this, we find that the condition for the modulational growth and the existence condition are consistent with the result. Drift breathers are excited when those conditions are met. In experiments where these conditions are not satisfied, no meaningful correlation between theory and experiment was found.

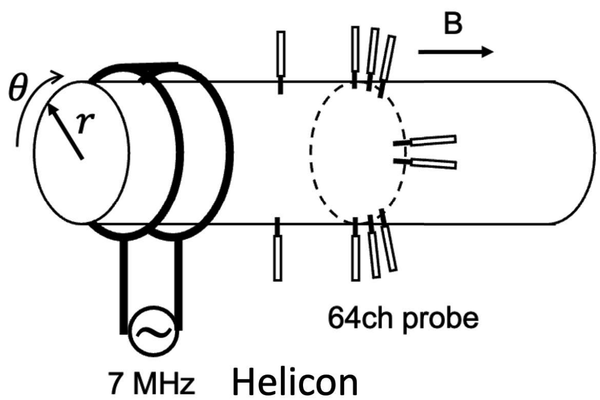

Fig. 3: A schematic diagram for the experimental device, PANTA.

The excitation of drift breathers has several implications on magnetic confinement. First, drift waves are of interest since they are directly tied to transport. By developing into nonlinear breathers, drift waves introduce intermittency in the dynamics of turbulence and transport in fusion plasmas. As demonstrated by data analysis, the excitation of drift breathers enhances particle flux transiently. The flux is amplified by a factor of 2 or so. This increase is transient, and after breathers disappear, the flux decreases to its original value. This is an interesting and relevant feature for magnetic fusion. In fact, fusion plasmas pose a challenge on transport; good confinement (i.e. low transport) is required for confinement perspective, while too good confinement introduces additional problems such as sudden release of heat, impurity or ash accumulation in plasmas. Transient increase may be a favorable feature from this point of view, since impurities/ash or excess of heat can be released via breather excitation. In this regard, there is an extension of the research to include impurity components for the excitation of breathers[7]. The analysis indicates that as impurity concentration increases, the breather excitation becomes easier and impurities may be self-regulated. This is a theoretical prediction to be validated in experiments in future.

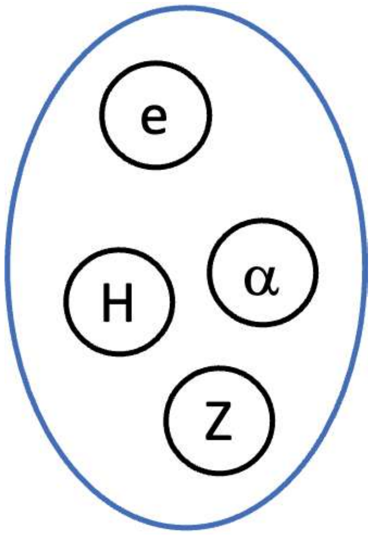

Fig. 4: Plasmas with multiple ion components. In practice, plasmas contain electrons (e), fuel ions (usually hydrogen, H), fusion products (α particle), and impurities (Z, Carbon, Tungsten, etc).

3 Outlook/Future directions

3.1 Spatially localized solutions

There is considerable room for further extension. In this work, we have focused on the case of streamer excitation. In this case, the spatial boundary condition is periodic and Akhmediev breathers are naturally excited as a consequence of modulational instability of underlying drift waves. On the other hand, another important flow, known as a zonal flow, exists in magnetized plasmas. In fact, the regime in which zonal flows dominate yields dynamics of drift waves similar to those described by the 1D NLS. Thus modulational pumping of zonal flows is likely. Although this is analogous to the pumping of streamers via modulational instability, the nonlinear dynamics can be quite different. In particular, within the frameworkof the 1D NLS, we expect that a different type of nonlinear breather solution may be realized. This is because the relevant boundary condition differs for streamers and zonal flows. In the case of streamers, the spatial direction is in the azimuthal direction. Thus the periodic boundary condition is natural and Akhmediev breathers can be excited. In the case of zonal flows, however, the spatial direction is in the radial direction. Plasmas are bounded in this direction, and periodic boundary condition may not be suitable here. Rather, the effect of boundary may enter here and solutions are sought for with the spatially localized ($\psi \to 0$ as $x \to \infty$) boundary condition. In this case, the 1D NLS then admits another exact solution, namely the Kuznetsov-Ma breather, as

$$\psi(x,t) = A_0 e^{i\beta A_0^2 t} \left(\frac{\sqrt{2}\mu^2 \cos(\beta A_0^2 \rho t) + i\sqrt{2}\rho \sin(\beta A_0^2 \rho t)}{\sqrt{2+\mu^2}\cosh(K_\mu x) - \sqrt{2}\cos(\beta A_0^2 \rho t)} - 1 \right). \tag{13}$$

Here $K_\mu = \mu\sqrt{\beta A_0^2/\alpha}$ and μ is a parameter associated with the amplification factor. This solution exhibits nonlinear oscillation in time while remaining spatially localized. A nonlinear oscillation (Limit cycle) associated with the coupled dynamics of drift waves and zonal flows has indeed been observed in experiments. There are various zonal structures, which are generated by an isotropic modulation in the radial direction, in fusion plasmas. The nonlinear stage of the coupled dynamics of drift waves, zonal flows, and Geodesic Acoustic Modes (GAMs) may be characterized within the framework discussed here.

3.2 Electromagnetic drift-Alfven waves

Another relevant direction is to seek for the relation to electromagnetic bursts, observed in various plasmas. This requires the extension of electrostatic models to include the effect of magnetic fluctuations[13]. To do so, we consider a simplified model by including only the perpendicular component of fluctuating magnetic field. Then magnetic and electric fields are written as

$$\mathbf{B} = B_0\hat{z} + \tilde{\mathbf{B}} = B_0\hat{z} + \nabla\tilde{A}_\parallel \times \hat{z}, \tag{14a}$$

$$\tilde{\mathbf{E}} = -\nabla_\perp\tilde{\phi} + \hat{z}\left(-\nabla_\parallel\tilde{\phi} - \frac{1}{c}\frac{\partial}{\partial t}\tilde{A}_\parallel\right). \tag{14b}$$

B_0 is an equilibrium field and $\tilde{\mathbf{B}} = \nabla\tilde{A}_\parallel \times \hat{z}$ is the perpendicular component of fluctuating magnetic field. Electric field is then quasi-electro static, i.e. the perpendicular electric field is electrostatic, $\tilde{\mathbf{E}}_\perp = -\nabla_\perp\tilde{\phi}$, and the parallel electric field is electromagnetic, $\tilde{E}_\parallel = -\nabla_\parallel\tilde{\phi} - (1/c)\partial\tilde{A}_\parallel/\partial t$. Within this approximation, the compressional Alfven wave is neglected, allowing us to focus on the dynamics of shear Alfven waves.

The dynamics of electromagnetic fluctuation is then described by

$$\frac{d}{dt}\rho_s^2\nabla_\perp^2\frac{e\tilde{\phi}}{T_e} = \frac{1}{en_0}\nabla_\parallel\tilde{J}_\parallel = -c\nabla_\parallel\lambda_{De}^2\nabla_\perp^2\frac{e\tilde{A}_\parallel}{T_e}, \tag{14c}$$

$$\frac{d}{dt}\frac{\tilde{n}_e}{n_0} + v_*\frac{\partial}{\partial y}\frac{e\tilde{\phi}}{T_e} = \frac{1}{en_0}\nabla_\parallel\tilde{J}_\parallel = -c\nabla_\parallel\lambda_{De}^2\nabla_\perp^2\frac{e\tilde{A}_\parallel}{T_e}, \tag{14d}$$

$$0 = -\mathbf{B}\cdot\nabla p_e - en_e\mathbf{B}\cdot\tilde{\mathbf{E}}. \tag{14e}$$

The model consists of the quasi-neutrality condition $\nabla\cdot\tilde{\mathbf{J}} = 0$, the electron continuity equation, and then the parallel force balance of electrons. The parallel force balance can be viewed as effective Ohm's law. This is a natural and the simplest extension of Hasegawa-Mima model (Eq.(1)) to include electromagnetic fluctuation. HM model is recovered for small $\tilde{\mathbf{B}}$ and adiabatic electrons. The relevant waves are then drift-Alfven waves, whose dispersion relation is given by

$$\frac{\omega(\omega-\omega_{*e})}{v_A^2k_\parallel^2} = 1 + \rho_s^2k_\perp^2 - \frac{\omega_{*e}}{\omega}. \tag{15}$$

This includes electrostatic drift waves ($\omega \cong \omega_{*e}/(1+\rho_s^2k_\perp^2)$ for $\omega_{*e} \ll k_\parallel v_A$) and kinetic shear Alfven waves ($\omega^2 \cong k_\parallel^2v_A^2(1+\rho_s^2k_\perp^2)$ for $\nabla n \to 0$ i.e. $\omega_{*e} \to 0$).

The nonlinear evolution of zonal flows and fields are described by

$$\frac{\partial}{\partial t}\rho_s^2\nabla_\perp^2\frac{e\tilde{\phi}}{T_e} = -\rho_sc_s\hat{z}\times\nabla\frac{e\tilde{\phi}}{T_e}\cdot\nabla\rho_s^2\nabla_\perp^2\frac{e\tilde{\phi}}{T_e} - \frac{1}{en_0}\frac{\nabla\tilde{A}_\parallel\times\hat{z}}{B_0}\cdot\nabla\frac{c}{4\pi}\nabla_\perp^2\tilde{A}_\parallel, \tag{16a}$$

$$\begin{aligned}\frac{\partial}{\partial t}\frac{e\tilde{A}_\parallel}{T_e} = &-\rho_sc_s\hat{z}\times\nabla\frac{e\tilde{A}_\parallel}{T_e}\cdot\nabla\left(\frac{\tilde{n}_e}{n_0}-\frac{e\tilde{\phi}}{T_e}\right) + \rho_sc_s\hat{z}\times\nabla\frac{e\tilde{\phi}}{T_e}\cdot\nabla\delta_{pe}^2\nabla_\perp^2\frac{e\tilde{A}_\parallel}{T_e} \\ &- \frac{\tilde{n}_e}{n_0}\left(c\nabla_{\parallel 0}\frac{e\tilde{\phi}}{T_e} + \frac{\partial}{\partial t}\frac{e\tilde{A}_\parallel}{T_e}\right).\end{aligned} \tag{16b}$$

Note that the density field is weak, since $n_{ZF} \sim O(q_\perp^2\rho_s^2)$ where $q_\perp$ is the typical wave number of zonal structures. The flow field evolves from the competition between Reynolds stress and Maxwell stress. The magnetic fluctuation evolves from various processes. The first is the magnetic flutter effect. This is related to meandering of magnetic field. Electrons move along the meandering field and feel pressure from density perturbation, which leads to an effective forcing along the magnetic field. The second term is related to the flux of electron parallel momentum. This term involves electron inertia, which appears through the dependence on the electron skin depth δ_{pe}. Thus the contribution from this term becomes important for small scales. The last term is related to the parallel acceleration of electrons. The role of the last term is not explored before, and will be investigated further in future study.

Zonal structures can be excited from drift-Alfven waves. As discussed in detail above, these zonal structures can feed back on the original waves. Within this framework, the excitation of breathers is a natural consequence of the nonlinear dynamics. Breathers can be excited from drift wave branch with zonal flow feedback. This breather can perturb magnetic field, which can lead to an abrupt change of the observed magnetic signal. Another route for exciting abrupt response of magnetic field may be related to the nonlinear evolution of drift-Alfven waves. The nonlinear excitation of electromagnetic breather in this context remains to be shown.

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