Nonlinear characteristics of mediator and streamer in linear magnetized plasmas

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The nonlinearly developed structures are universal in plasma physics. In magnetized plasmas, drift waves nonlinearly couple with each other and form the structures, such as zonal flow and streamer [1]. These structures are also important for fusion, since they give a strong impact to the transport. Especially for the confinement degradation, radially elongated and azimuthally localized structure of streamer is important, since the streamer enhances radial transport. Streamer was first found in a linear magnetized plasma, through the observation of radially elongated drift waves modulated by low frequency fluctuations, called mediator [2]. Recently, the mediator has been found to have higher harmonic components, although it was simply treated as a sinusoidal wave. Moreover, by taking into account the nonlinear characteristics of the mediator, the nonlinear feature of the streamer structure is extracted [3]. The frequency of fundamental and higher harmonic components of the streamer is identical to that of the mediator. This indicates the streamer is also modulated through higher harmonic components of mediator as well as through fundamental components. We also observed that the mediator and streamer should have a general character of the solitons; the amplitude increase inversely with the square of the width of the half maximum. The paper presents the new findings of mediator and streamer in linear magnetized plasmas.

The experiment was performed in a linear device, PANTA. The device length is 4m and argon plasma is excited in the Helicon wave discharge of 3kW/7MHz. Axial magnetic field is generated by the seventeen solenoid coils, which can control the magnetic field strength from 0.03T to 0.15T. The diameter of the plasma is around 10 cm, and the central electron density and electron temperature is around 1×10^{19} m^{-3} and 3eV, respectively. The ion saturation current and the floating potential are measured through azimuthally aligned 64-channel Langmuir probe tips (64ch probe) at r = 4cm.

The nonlinear waveform of meditator is extracted through the conditional averaging. Since the harmonic components are locked with their phase to the fundamental, the tracking the phase of the fundamental components is useful for detecting the nonlinear waveform. Due to the better signal-to-noise ratio, the ion saturation current fluctuations are used for the analysis. Figure 1(a) shows the raw signal of the fluctuations and modulated envelope structure, namely streamer envelope. For extracting the nonlinear waveform of mediator and streamer envelope, the trigger for conditional average is chosen when the phase of the fundamental component of mediator is zero. Here, the frequency of the fundamental components of the mediator is found at f = 1.4kHz, as shown in the spectrum of the raw signal in Fig. 1(c). Then, the conditional averaging is applied to the raw signal, and we finally obtained the typical waveform of the mediator, as shown in Fig. 1(b). Since the fundamental component of the streamer envelope is also at f = 1.4kHz (as shown in red line in Fig. 1(c)), the waveform of streamer envelope is also extracted through conditional

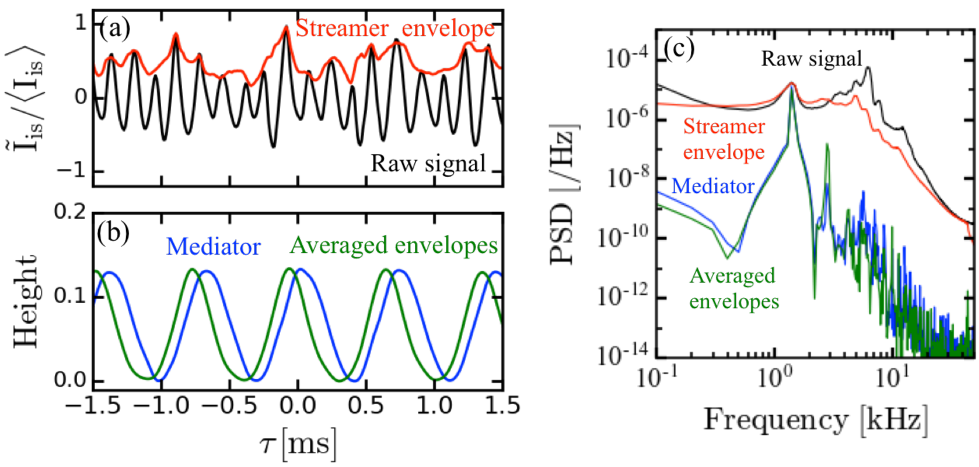

Fig. 1. (a) Normalized fluctuation of ion saturation current (black) and streamer envelope (red) are shown. The origin of time, τ = 0ms, corresponds when the phase of mediator passes 0. (b) The conditionally averaged mediator (blue) and streamer envelope (green) is extracted. The base level is adjusted to zero, and thus "height" is defined. (c) Power spectra of the raw signal, streamer envelope, the conditionally averaged mediator and conditionally averaged streamer envelope. In this case, magnetic field strength is 0.08T.

averaging by providing the same trigger, which is used in the conditional averaging of mediator. Obtained waveform of streamer envelope is shown in Fig. 1(b). Here, the base level of the waveform is adjusted to zero by subtracting its minimum value, and the peak value of the wave is termed "height". The spectra of the conditionally averaged mediator and streamer envelope are shown in Fig. 1(c). In addition to the peaks at the fundamental component of the waves at 1.4kHz, there are clear peaks at the second harmonic frequency of 2.8kHz for both of mediator and streamer envelope. This indicates that the modulation of the drift waves to generate streamer is not only through fundamental components of the mediator, but also through higher harmonics components of the mediator.

The nonlinear waveforms of mediator and streamer change their characters with the magnetic field strength. Figure 2 shows the examples of the waveform of streamer envelope for three values of magnetic field B = 0.06, 0.08 and 0.10T. The figure indicates that the height and the degree of sharpness increase with magnetic field strength. For quantifying the degree of sharpness, the anharmonicity α is defined as $\alpha = C_{down}/C_{up}$, where C_{up} and C_{down} represents the full width of half maximum of the local maximum and that of half minimum of the local minimum, respectively. The anharmonicity increases as the deviation from the sinusoidal wave ($\alpha = 1$) becomes larger. The anharmonicity for this figure is 1.0, 1.4 and 1.5 for B = 0.06, 0.08 and 0.10T, respectively.

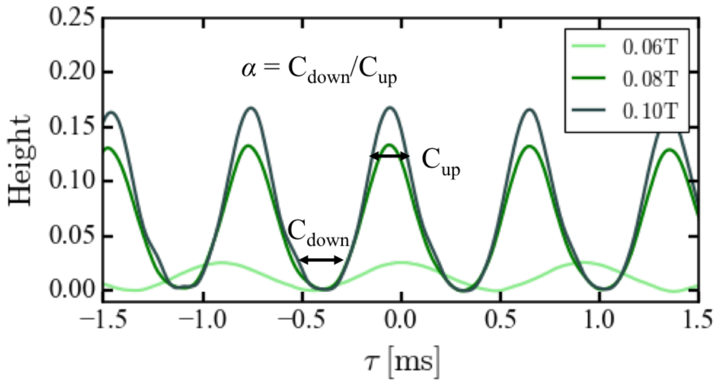

Fig. 2. The conditionally averaged waveforms of streamer envelope with magnetic field B = 0.06, 0.08 and 0.10T. The degree of nonlinearity is estimated to calculate anharmonicity α, which is defined by the ratio of full width of half maximum of the local minimum C_{down} to local maximum C_{up}.

The height and anharmonicity α for the mediator and streamer envelope are shown in the Figure. 3(a) and (b), respectively. The figure shows clear dependence that the height and anharmonicity increase with magnetic field strength for both mediator and streamer envelope. It is noted that here the height is normalized with the drift waves amplitude (root-mean-squared of the fluctuations), in order to remove the effect of the changing of the background plasma.

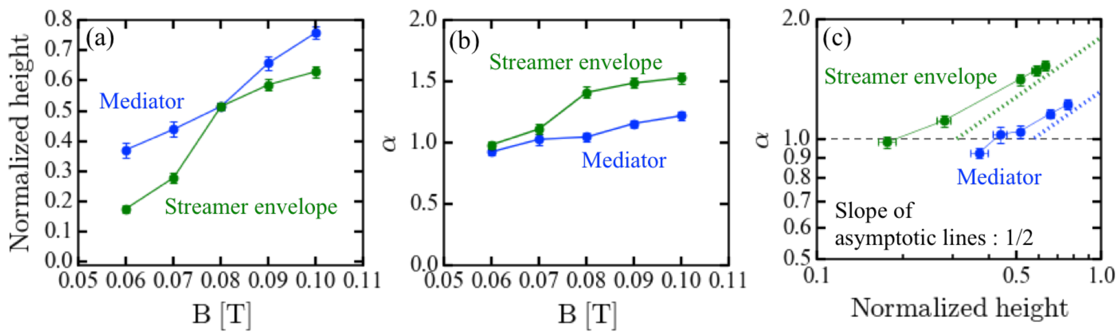

Fig. 3. Magnetic field dependence of (a) normalized height and (b) anharmonicity α for mediator and streamer envelope are shown. The relation between normalized height and anharmonicity is shown. The slope of the asymptotic lines is 0.5, which indicates that the height increase proportionally to squared α.

Next, the magnetic field is eliminated, and the direct relationship between the height and anharmonicity is considered for both waves. Figure 3(c) shows that for the both heights of mediator and streamer envelope increase with the anharmonicitiy α. In the figure, the slope of the asymptotic lines are 0.5, and this indicates that the height increase proportionally to the squared α. This is a common feature known for solitons, such as the solution of the Korteweg-de-Vries equation.

For the summary, the conditional averaging is applied to extract the nonlinear characteristics in the waveform of mediator and streamer envelope. From the modulations through the higher harmonic components of the mediator, envelopes of the streamer also contain higher harmonic components. The degree of nonlinearity is estimated by calculating the anharmonicitiy. The heights of both waves are found to increase with the anharmonicity, which is commonly valid for the solitons.

Acknowledgments

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