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Coherency Properties of Strong Langmuir Turbulence

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Abstract

Strongly correlated Langmuir wave collapse has been observed in two dimensional simulations of Zakharov's model in a regime characterized by strong ion sound wave damping and an external drive frequency, ω_0, close to but less than the plasma frequency, $[\omega_p - \omega_0]/\omega_0 \simeq \varepsilon$ with $\varepsilon \approx 0.005$. Caviton-caviton interactions induce temporal correlations between different collapse sites on a time scale the order of a collapse cycle, and on a longer time scale site locations migrate possibly leading to strong spatial correlations. Certain features[1] of ionospheric incoherent scatter radar (ISR) spectra are consistent with such correlations.

The conventional picture of "strong plasma turbulence" is of an incoherent nonlinear collection of "waves". In the case of strong Langmuir wave turbulence (SLT), however, it is well known[2] that Langmuir waves may organize into "solitons" which collapse in dimensions ≥ 2. Collapse itself is stable in the sense that all collapses are asymptotically self similar, with the energy taken into collapse merely determining an overall scale. There may be several stable collapse geometries, but there is some numerical evidence[3] that the range of geometries is relatively tame (i.e. oblate versus prolate spheroids). For purposes of this paper the following discussion will be limited to the case of strong ion sound wave damping, e.g. $\nu_i/kc_s > 0.6$.

Besides the intrinsic coherency of the asymptotic collapse process we have found for the case of an isolated collapse site that the nucleation-collapse-burnout cycle is periodic in time[4]. For this temporal coherence to be physically significant it must survive when interactions with other collapse sites are allowed. We have found[5] that this *is* the case when the plasma is overdense with respect to an external electric field with frequency ω_0, as described in the abstract. When the plasma is overdense, the generation of Langmuir radiation (i.e. freely propagating as opposed to spatially localized modes) is inefficient. Therefore the interaction of collapse sites is primarily through the exchange of ion sound waves generated by collapse. If collapse sites are separated by several caviton diameters, then the sound waves impinging on a given collapse site are almost spatially uniform, and their primary effect is to alter the frequency of the localized mode which determines nucleation. As a result, caviton-caviton interaction leads to a slight advance or retardation of a given collapse. The cumulative effect of many such perturbations is typically found to induce temporal correlations between neighboring collapse sites after a few collapse cycles. Depending on the spatial pattern of the collapse sites, it is possible to find cases where neighboring cycles are 180° out of phase, and cases where there is global synchronization. Over many cycles, collapse sites are observed to migrate, with this time scale longer the more overdense the plasma. The number of collapse sites may also change. In the overdense regime there may not be a unique steady turbulent state. Because of limited computer resources our simulations typically have fewer than 10 sites. As a result, the behavior of truly large collections of sites, as in the ionospheric experiments described below, is unknown.

One of the applications of SLT theory, in particular the coherency properties described above, is to the ISR spectra measured in ionospheric heating experiments[6]. The results of our research in this area[5,6] can be summarized as follows:

1) States of SLT can be sustained for heater intensities well below the threshold for parametric instabilities.

2) In these states of SLT a major part of the spectrum of high frequency density fluctuations is contained in localized states in the case of

strong ion sound wave damping which is appropriate to the ionosphere.

3) This state of SLT is sustained by a local nucleation process which leads to collapse.

4) A relatively weak spectral feature, which we call the "free mode" peak, lying above the heater frequency, corresponds to the free Langmuir wave dispersion relation, and these waves are produced as a byproduct of nucleation and collapse.

5) Within the framework of Zakharov's model of SLT, the late time (tens of milliseconds) observed ISR spectra have sharp features which can only be produced by cavitons which are strongly correlated in space and time.

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