Indirect Detection of Charged Space Debris via Nonlinear Wave Excitations

Abhijit Sen [(1)], Sanat Tiwari [(1)], Sanjay Mishra [(1)] and Predhiman Kaw [(1)]
(1) Institute for Plasma Research, Bhat, Gandhinagar 382428, India

The detection and effective tracking of debris objects in the LEO and GEO regions are topics of much current interest and study in the area of space situational awareness in view of the rapid growth of the debris population and the concomitant threat they pose to active space assets. A major limitation of the present widely employed optical detection techniques is that they are only effective for objects that are larger than 10 cms in size. Since even a centimeter sized object can cause significant damage to a spacecraft it is important to develop alternative methods of detecting small sized objects. We propose and discuss an indirect method that relies on the detection of non-linear waves excited in the ambient plasma by the orbiting charged debris. The charging of the debris objects is a consequence of the flow of electron and ion currents on them and due to other charging processes like the photoemission of electrons resulting from the exposure to solar radiation. A streaming charged debris object constitutes a forcing disturbance that can excite various collective excitations in the ambient plasma medium. A familiar occurrence is the excitation of linear wake fields behind the object. The detection of these low frequency linear excitations in the ionosphere can however be quite challenging due to their low amplitudes, interference effects between wakes from neighboring objects and their rapid decay due to dispersive effects. Since the debris objects are highly charged they can cause a perturbation large enough to induce nonlinear excitations in the plasma medium and these excitations can be long-lived and more easily detectable. We investigate one such scenario for debris objects moving faster than the ion sound speed, which is generally the case in the low earth orbit (LEO) region, whose dynamics can be described by a model nonlinear evolution equation that takes the form of a forced Korteweg de Vries (fKdV) equation. The streaming objects can then give rise to a remarkable phenomenon, namely, the excitation of advancing solitary waves in the upstream region apart from the weak dispersive excitations (wake fields) in the down stream region. Such excitations have been predicted and observed in the past in fluid flow experiments but have not received any attention so far in the plasma physics community. These precursor solitary waves are stable long lived entities whose detection using ground based methods could provide a useful means of indirectly detecting the presence of small sized charged debris objects. We present various exact analytic as well as numerical solutions of the model equation, estimate their amplitudes in the LEO/GEO environments and then discuss the feasibility of detecting them using ground based radar measurements.