4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Modeling cosmic radio bursts via plasma dipole oscillation

M.S. Hur[1], T. Kang[1], H.S. Song[1], K. Yu[2], H. Suk[3], S. Yoffe[4], B. Ersfeld[4], D.A. Jaroszynski[4]
[1] Dept. Phys. and CHEA, UNIST, [2]CSI, Brookhaven National Lab., [3]Dept. Phys. Photon Sci., GIST, [4]Dept. Phys., SUPA and Univ. Strathclyde
e-mail (speaker): mshur@unist.ac.kr

Radio bursts are abundant in our solar system and in the deep space. The mechanism of the solar radio bursts (SRB) is understood relatively well. A commonly-accepted explanation of the SRB is that it originates from Langmuir waves driven by energetic electrons via stream instabilities. Diverse mechanisms have been suggested for the conversion of the Langmuir energy to electromagnetic energy. However, the conversion efficiency of the Langmuir-radio waves still remains controversial. Similar radio bursts, which are believed to originate from point-like (on the astrophysical scale) sources in deep space are referred to as fast-radio-bursts (FRBs). However, the precise source of FRB remains obscure.

Experimental efforts to investigate space physics in the laboratory [1] are focused on understanding cosmic radio bursts; recent laser-plasma experiments studying second harmonic generation verified the scenario of LW→LW′+IAW′/ LW+LW′ → $EM_{2\omega_p}$[2]. These laser-driven experiments are able to examine scenarios of cosmic radio burst in well-controlled studies.

In this presentation, we introduce a similar laboratory scale idea to explain a different mechanism of cosmic radio bursts; the radiation bursts from plasma dipole oscillation (PDO). The PDO is a stand-alone plasma oscillation embedded in plasma. To generate a PDO, two slightly detuned laser pulses are made to collide in the middle of a region containing plasma to generate a moving ponderomotive potential train in a small localised volume around the pulse collision point. Electrons riding on the potential train during the pulse collision time results in the displacement of a macroscopic localised bunch of electrons which results in successive plasma oscillations of the bunch at the local plasma frequency. The overall procedure resembles the drag and release of an oscillating mass fastened to a spring. The oscillating electron bunch emits burst-like radiation by the antenna mechanism [3]. Figure 1 represents an example of three dimensional PIC simulation of the radiation burst from the PDO.

An analytic study to characterise PDO-radiation found it to have several common features with the cosmic radio bursts. Of particular note is that the radiation frequency exactly matches the local plasma frequency at the position of the PDO. This feature has been successfully explained using a slab-like model [4]. Moreover, it has been shown that the PDO has features in addition to those of the simple slab model. Because of its nonlinearity, it intrinsically contains high-order poles that are responsible for high harmonic emission. The simultaneous emission at the fundamental and second harmonic arising from a single PDO mechanism has strong merit as a candidate of source of the cosmic radio bursts. Furthermore, when the PDO is generated in a magnetized plasma, the emission frequency and polarization has much more rich physics; the plasma frequency and harmonics, two cutoff's of the X-mode, upper hybrid mode, sub-frequencies by the nonlinearity, along with linear and elliptic polarizations.

The report on electron beam-beam interaction for generation of the second harmonic [5] by the two-plasmon merger strongly implies that there is a high chance of PDO generation in an astrophysical environment in addition to the laboratory.

In summary, the generation of the PDO in laboratory-scale plasmas using laser pulses has been demonstrated by 2D and 3D particle-in-cell simulations. We have also studied the nonlinearity of the PDO in magnetized plasmas. Opportunities for the laboratory study of the cosmic radio burst via PDO concept is discussed.

References

[1] G.G. Howes, arXiv:1802.04154v1 (2018).
[2] J.-R. Marquès et al., Phys. Rev. Lett. 124, 135001 (2020).
[3] D.M. Malaspina et al., Astrophys. J. 755:45 (2012).
[4] Kwon et al., Sci. Rep. 8, 145 (2018).
[5] V.V. Annenkov et al., Phys. Plasmas 25, 113110 (2018).

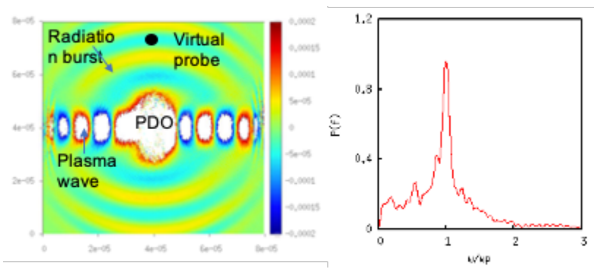

Figure 1. 3D PIC simulation of a radiation burst from the PDO in a magnetized plasma. (a) Radiation pattern on a *x-y* slice crossing the PDO centre. (b) Spectrum of the electric field acquired from a virtual probe located outside the PDO.