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Intense Laser Radiation in Plasmas

L. Stenflo and P. K. Shukla

Department of Plasma Physics, Umeå University, SE-90187 Umeå, Sweden

R. Bingham

Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 0QX, United Kingdom

Abstract

The possibility of a new low-frequency intense electromagnetic wave in a multi-component magnetized plasma is pointed out. The wave frequency depends significantly on the wave electric field. Strong electromagnetic waves can be associated with the powerful pulsar signals from the surfaces of some neutron stars.

The interaction of intense electromagnetic waves with ionized matters and plasmas is a fundamental topic of interest in many areas of sciences ranging from astrophysics to inertial confinement fusion as well as to plasma based charged particle accelerators. The interaction physics is a rich test bed for many basic processes in plasmas. Specifically, the interaction between intense electromagnetic waves and an electron-ion plasma gives rise to a number of relativistic and nonlinear effects such as parametric instabilities [1], generation of intense electric field gradients and magnetic fields, and stimulated backscattered harmonic generation. When the electromagnetic wave intensity exceeds 10^{18} watts/cm^2, the relativistic electron mass variation becomes important. The physics of relativistic nonlinear effects in plasmas has been discussed in a review article [2] where their importance to laboratory and astrophysical plasmas has been emphasized.

We report here a novel low-frequency electromagnetic wave in the magnetized plasma universe composed of electrons, positrons, heavy ions/dust grains, and extremely high-energy gamma ray bursts. Such a plasma can appear in magnetized neutrons stars, in the early universe, as well as in many astrophysical objects of our galaxy. It is a widely held view that the high-energy radiation can generate electron-positron pairs which are confined by the ambient magnetic field. The radiation pressure can cause acceleration of charged particles to extremely high energies and there are also space charge fields and currents in the plasmas. On the time scales of seconds, the pairs do not annihilate and there appears new low-frequency electromagnetic waves whose frequencies depend on the wave electric fields. The physical properties of one of these waves is described below.

We suppose that our low-frequency (in comparison with the electron gyrofrequency) electromagnetic wave is circularly polarized and that it propagates along an external magnetic field $\mathbf{B}_0$. Then the general dispersion relation is [2]

$$\frac{k^2c^2}{\omega^2} = 1 - \sum_j \frac{\omega_{pj}^2}{\omega(\omega\gamma_j + \omega_{cj})}, \tag{1}$$

where ω is the wave frequency, k is the wave number, $\omega_{pj} = (4\pi n_j q_j^2/m_{0j})^{1/2}$ and $\omega_{cj} = q_j B_0/m_{0j}c$ are the plasma and gyrofrequencies of the species j, q_j is the charge, m_{0j} is the rest mass, n_j is the density of the species j, and c is the speed of light. The relation between γ_j and the electromagnetic wave electric field E_0 is given by

$$\gamma_j^2 = 1 + \frac{\omega_{Ej}^2\gamma_j^2}{(\omega\gamma_j + \omega_{cj})^2}, \tag{2}$$

where $\omega_{Ej} = |q_j E_0|/m_{j0}c$.

In a pair plasma (where j equals e for the electrons and p for the positrons) we have $m_{0e} = m_{0p} (= m_0)$ and $\omega_{Ee} = \omega_{Ep} (= \omega_E)$. We there consider a low-frequency wave where $\omega \ll |\omega_{cp} - \omega_E|$. When the intensity of that low phase velocity (in comparison with c) wave is sufficiently high, so that the wave electric field E_0 is comparable to B_0, then eq. (1) transforms into the dispersion relation

$$\omega = \frac{k^2c^2\omega_E}{\omega_{pp}^2(1 + n_e E_0/n_p B_0)}, \tag{3}$$

where ω_{pp} is the positron plasma frequency. It is remarkable that the wave frequency, given by eq. (3), is proportional to the wave electric field (when $E_0 < B_0$) and that the polarization current associated with the relativistic positron mass variation is primarily responsible for the low-frequency electromagnetic wave reported here. Similar behaviour has also been found in other contexts [3]. For illustrative purposes, we note that for typical Crab nebula parameters [4] where B_0 is is of the order of one milli gauss, $E_0 \sim B_0$, $n_p \sim n_e \sim 10^{-3}$ cm^{-3}, the wave frequencies (ω) are of the order of one hundred fifty s^{-1} (which is close to the frequency of the rotation of the Crab pulsar) for wavelengths of the order of thousands of kilometers. It is possible that our waves can be associated with the powerful pulsar signals from the surfaces of some neutron stars including the Crab nebula. The present electromagnetic waves may also arise in laboratory plasmas in the presence of powerful laser beams which create pairs and strong magnetic fields.

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References

[1] W. L. Kruer, *The Physics of Laser Plasma Interactions* (Addison Wesley, Redwood City, 1988).

[2] P. K. Shukla, N. N. Rao, M. Y. Yu, and N. L. Tsintsadze, Phys. Rep. **138**, 1 (1986).

[3] L. Stenflo and P. K. Shukla, IEEE Trans. Plasma Sci. **29**, 208 (2001).

[4] J. Bolton, Nature **162**, 141 (1948).