Astrophys Space Sci (2013) 346:149–153
DOI 10.1007/s10509-013-1416-3

ORIGINAL ARTICLE

Modulational behavior of electromagnetic waves in ultra-relativistic electron-positron plasmas

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Received: 31 January 2013 / Accepted: 6 March 2013 / Published online: 16 March 2013

Abstract The dynamical properties of electromagnetic (EM) waves in ultra-relativistic electron-positron (EP) plasmas are analytically investigated on the basis of the nonlinear governing equations obtained from a kinetic way. It is shown that the EM wave envelope will collapse and be trapped into a localized region for the modulation interaction with low frequency density variation induced by ponderomotive force. The correlation between the localized strong wave field and the pulsar radio emission is discussed.

Keywords Modulational instability · Electromagnetic wave · Electron-positron plasma · Collapse

1 Introduction

Recently, Chen et al. (2009) reported that positrons with energy to be MeV and density to be 10^{16} cm^{-3} have been created in the interaction of short ultraintense laser pulses with gold targets. As represents a big step toward the experimental investigation of the nonlinear phenomena in relativistic electron-positron (EP) plasmas.

The interaction of EM wave with non-relativistic and relativistic EP plasmas has aroused intense interest, due to the fact that the EP plasmas are considered to be existed near the polar cap of a pulsar (Goldreich and Julian 1969; Michel 1982), in the gamma-ray bursts (Piran 1999; 2004), as well as in the early universe (Ress 1983; Misner et al. 1973). Chian and Kennel (1983) firstly proposed the self-modulational instability of strong EM waves in an EP plasma to explain the microstructure of pulsar radio pulses. Since then there have many literatures about the nonlinear behavior of EM waves in relativistic EP plasmas (Asseo 1984; Stenflo et al. 1985; Shukla et al. 1986, 2004; Lakhina and Tsintsadze 1990; Berezhiani and Mahajan 1995; Kartal et al. 1996; Gratton et al. 1997; Lontano et al. 2001; Tatsuno et al. 2003, 2007; Munoz 2004). Berezhiani and Mahajan (1994, 1995) studied the nonlinear propagation of relativistically strong EM radiation in a hot EP plasma with small fraction ions. They found that EP plasma supports the propagation of nondiffracting and nondispersive EM pulses (light bullets) with large density bunching. Lontano et al. (2001) studied the possibility of EM radiation trapping in the form soliton like structures in a hot EP plasma on the basis of a fully relativistic, hydrodynamic approach, limited to a one-dimensional geometry. Tatsuno et al. (2007) investigated nonlinear interaction of an intense EM beam with relativistically hot electron–positron plasma by invoking the variational principle and numerical simulation. Their analysis shows the possibilities of trapping and wave-breaking of EM beams. Just as most of the papers related to the wave plasma interaction, these papers are based on fluid model.

However, an important property that distinguishes high temperature plasmas from normal fluids is that the plasmas are to a first approximation collisionless (O'Neil and Coroniti 1999). In space and astrophysical plasmas, the mean-free-path can easily exceed the dimensions of the structures of interest. That means the plasma is in a collisionless state. In ultra-relativistic EP plasmas, the positron (or electron) mean free path is generally much larger than the scale of interest. The fluid model has an advantage which can avoid the complexity of the phase-space dynamics. However, it is

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