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Possibility of Model Experiments on Relativistic Plasama Phenomena with Ultra-intense Lasers

相対論プラズマ現象の超高強度レーザーによる模擬実験の可能性

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With use of ultra-intense lasers, we can efficiently convert the energy of lasers to that of relativistic electrons with average energy of around 10 MeV. These relativistic electrons produce positron through the interactions with nuclei. We can create electron-positron plasmas with average Lorentz factor of around 10. This value is almost the same as seen in the jet from Active Galactic Nucleus (AGN). In addition, we can also study Weibel type instability which is thought to be important in the Gamma-ray bursts. We describe the present status of laser produced pair plasma and its usage for model experiment for astrophysical phenomena.

1. Introduction

It is clear that the high power laser has grown as a new tool to investigate an advanced physics in extreme conditions. This rapid growth of the laser technology is partially driven by the need for laser fusion research and also by the invention of CPA (Chirped Pulse Amplification) technology [1]. I have strong confidence that the lasers could be the second accelerator to open a new field of the fundamental science, and of course they are also used for many applications in science and industry. So-called Laboratory Astrophysics with intense lasers has been proposed and many case studies has been done [2]. One of the interesting case is the use of relativistic plasma for studying high-energy astrophysics in laboratory. For example, it is the creation of anti-matter by use of ultra-intense lasers [3] and electron-positron plasma formation. There are full of electron-positron plasmas near Black Hole and also in AGNs (Active Galactic Nuclei). We plan to do an experiment where the generated electron-positron plasma collides with imposed magnetic field or matter. Such experiment may be a model experiment of expanding fire-ball believed to be important as the energy source of the gamma-ray bursts [4]. At the same time, it is also interesting to trigger nuclear reaction processes [5].

2. Laser Produced Relativistic Plasma

When ultra-intense and ultra-short laser is irradiated on a solid target, we can assume that ions have no time to react and at rest. Through a variety of interaction processes, most of laser energy is converted into that of relativistic electrons. The injection of the relativistic electrons into the target induces the return currents by the background electrons, consequently a variety of instabilities being induced. Such instabilities accompanying with strong magnetic field are the origin of anomalous transport of the relativistic electrons.

In addition, the expansion of the substantial amount of relativistic electrons into vacuum is prohibited by the generation of the am-bipolar electrostatic field almost normal to the target surface. The relativistic electrons are confined and interact with target ions many times. In the interaction with nuclei, the quantum-electro-dynamic (QED) process can be seen, because the electron energy is far beyond the rest mass energy of electron. For example, high-energy γ-rays generated through Bremstrahlung process induce photo-nuclear reactions, and electron anti-matter positrons are created through QED process.

In later time after the impinging of the laser, the am-bipolar electrostatic field drives the acceleration of ions. Since the electrostatic potential of the am-bipolar field is of order of 10 MeV, the ions are accelerated up to such energy range with very narrow angle spread [6]. Good and compact ion beam source can be designed with the ultra-short pulse technique.

3. Positron Production

There are two processes which create positrons in the present situation. Trident process is a single process, while the Bethe-Heitler (BH) process is a two-stage process. In the BH process, namely, the electron energy is once converted to that of γ-ray and the γ-ray interacts with nucleus to create a pair. Which one contributes most to generate positrons has been studied [7].

The production of positron has already pointed out in early time [8], however, they just estimated the threshold laser intensity over which pair production occurs owing to the Trident process. They concluded that pairs are produced when the laser intensity is higher than 10^{19} W/cm^2. Liang et al considered the case when the high energy electrons are confined in a relatively thin gold foil and concluded that the Trident process is more important than the Bethe-Heitler process for the case of the foil with the thickness 1 μm [9]. On the other hand, Gryaznykh et al have considered the case of relatively thick target and concluded that the BH process is more important [10].

4. Modeling High-Energy Astrophysics

The relativistic electron-positron plasma is an essential ingredient in high energy astrophysics. In the high energy astrophysics, for example, the high energy physics in the matter near Black Holes should be studied. In general, the temperature of the matter is extremely high because of the conversion of the gravitational energy to thermal energy in the accretion disk surrounding the Black Holes.

The electron positron plasmas appear to be important in studying the plasmas over the surface of pulsars, near black holes, at the center of our galaxy, at the active galactic nuclei (AGN), and in the MeV epoch about one second after the Big Bang.

We propose to do a model experiment of the propagation of pair plasma jet in the gas modeling inter-stellar matter in order to study the propagation of AGN jets. We also proposed to study the Weibel instability and magnetic field structure formation in relativistic plasmas relating to the physics of the gamma-ray bursts.

More details will be presented in the conference.

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