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Experimental study on the origins of cosmic rays
宇宙線の起源に関する実験的研究

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Experimental study on the origins of cosmic rays is presented. One possible mechanism for the nonthermal acceleration of the extragalactic cosmic rays is wakefield acceleration. In the upstream of a relativistic collisionless shock, large amplitude electromagnetic (light) waves are considered to be excited and particles can be accelerated by turbulent wakefields. Numerical simulations show universal production of power-law spectra of the accelerated particles with an index of ~ 2. By substituting an intense laser pulse for the light waves in the upstreams of the astrophysical shocks, a model experiment was performed to prove the preceding numerical model. The result is equivalent to the numerical study and the first experimental proof of a model for cosmic ray acceleration.

1 Introduction

It is considered that the diffusive shock acceleration (DSA) is a standard acceleration mechanism for energetic particles or cosmic rays within our galaxy. In order to understand the dissipation and transport processes in the shock environments, collisionless shock formations have been investigated in laboratories [1, 2]. On the other hand, the origin of extragalactic cosmic rays has been a long standing unsolved issue. A possible candidate of the cosmic ray acceleration is the wakefield acceleration in astrophysical environments. For instance, efficient particle acceleration by wakefields induced by large amplitude precursor electromagnetic (light) waves in the upstream of relativistic perpendicular shock waves was reported[3]. In astrophysical plasmas, however, it is impossible to observe the field and particle quantities directly, which are crucial in the acceleration and transport of cosmic rays.

By performing two-dimensional particle-in-cell (PIC) simulations, a model experiment of cosmic ray acceleration due to an incoherent wakefield induced by an intense laser pulse was proposed [4], where the laser pulse is substituted for the large amplitude light waves in the astrophysical shocks. When the spatial scales of the laser pulse are larger than the plasma wavelength, relatively incoherent or quasi-turbulent walefield is excited and the electrons are nonthermally accelerated, resulting in power-law energy spectra with an index of ~ 2 independent of the laser intensity, the plasma density, and the pulse size. Although it used to be difficult to prove a model for cosmic ray acceleration so far, current laser technology allows us to prove the above model by laboratory experiments. Using an intense laser pulse for the astrophysical precursor light waves, the universality of power-law acceleration of relativistic electrons with respect to the plasma density has been experimentally proved [5, 6].

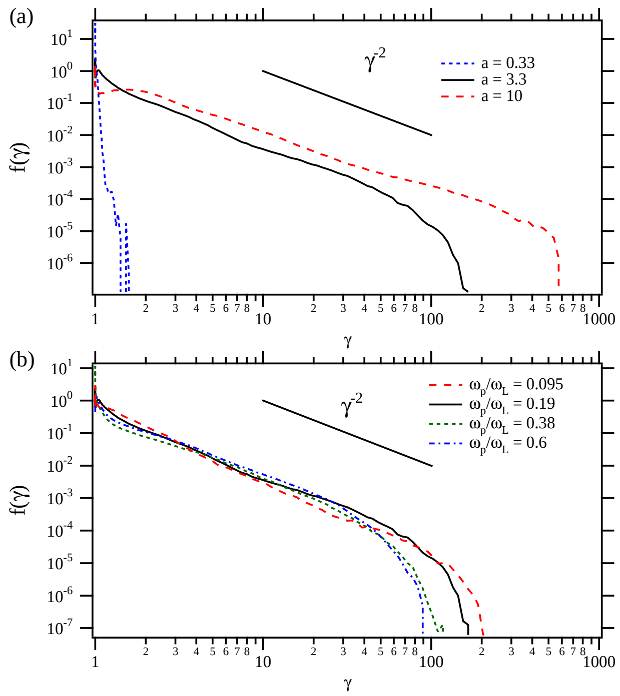

Figure 1: Energy distribution functions of electrons are shown with various (a) laser intensity and (b) plasma density. The spectra are well represented by a power law with an index of ~ 2.

2 Numerical simulations

We perform particle simulations in two spatial and three velocity dimensions. The details of the numerical conditions are found in [4]. Figure 1 shows the energy distribution functions of the electrons calculated by varying (a) the laser intensity and (b) the plasma density. In Fig. 1 (a) the larger intensity results in the larger acceleration. When the normalized laser intensity $a = 0.33$, the electrons are simply thermalized rather than the nonthermal acceleration. Except $a = 0.33$ the spectra are well represented by the power law with an index of ~ 2. The lower density results in the larger acceleration, however, the spectra are commonly characterized by the power law with an index of ~ 2.

3 Experiment

The experiment was performed using the PW laser system at the Institute of Laser Engineering at Osaka University. The details of the experimental setup and the diagnostics are found in [5, 6, 7]. Figure 2 shows three energy distribution functions of relativistic electrons generated for three different implosion energies with logarithmic scales. The maximum energies in the energy distribution

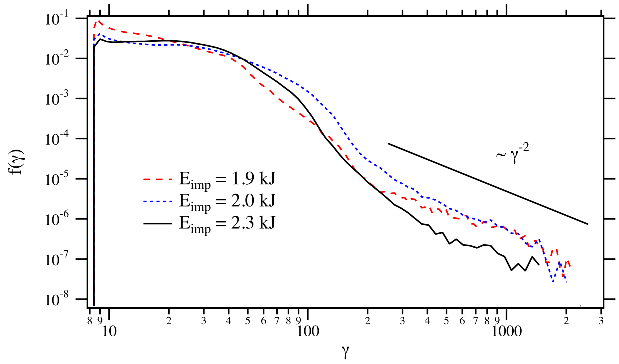

Figure 2: Energy distribution functions of the electrons in logarithmic scales.

functions were different for different implosion energies; the higher implosion energy was the lower maximum energy. The distribution functions consist of two parts; one is the thermal part and the other is the nonthermal part, which is represented as a power law. The nonthermal parts show a common feature, a power law with an index of ~ 2 independent of the plasma density.

4 Summary

We have presented results from numerical and experimental simulations of cosmic ray acceleration due to wakefield induced by an intense light pulse. In our numerical study, the electrons were nonthermally accelerated by the incoherent wakefield, resulting in a power-law spectrum with an index of ~ 2 independent of the plasma density [4]. Scaled laboratory experiment shows that energy distribution functions of electrons have a power-law component with an index of ~ 2 independent of the implosion energy or the plasma density [5, 6]. This is the first experimental proof of an analytic model of the cosmic ray acceleration.

References

[1] T. Morita *et al*, *PoP*, 17, 122702, 2010.

[2] Y. Kuramitsu *et al.*, *PRL*, 106, 175002, 2011.

[3] M. Hoshino, ApJ, 672, 940, 2008.

[4] Y. Kuramitsu *et al.*, ApJ, 682, L113, 2008.

[5] Y. Kuramitsu *et al.*, *PoP*, 18, 010701, 2011.

[6] Y. Kuramitsu *et al.*, *PRE*, 83, 026401, 2011.

[7] N. Nakanii *et al.*, *APL*, 93, 081501, 2008.