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高強度レーザーを用いた実験室宇宙物理学の進展：宇宙線加速
Recent Progress of Laboratory Astrophysics with Intense Lasers: Cosmic Ray Acceleration

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1 Introduction

Rapid progress of laser technologies allow us to explore space and astrophysical phenomena in laboratories. The so-called laboratory astrophysics was proposed in the end of 1990' and has been developed these decades over the world [1]. We have been working on collisionless shocks and magnetic reconnections with large laser facilities [2, 3, 4], and developing the relativistic regime with ultra intense short pulse lasers [5]. In this talk we briefly review the recent progress of the laboratory astrophysics, especially focusing on the origins and acceleration of cosmic rays.

2 Wakefield acceleration in the universe

While the diffusive shock acceleration or the first order Fermi acceleration has been widely accepted for the acceleration mechanism of galactic cosmic rays, the origins of extragalactic cosmic rays have been unsolved open question [6]. One possible mechanism accounting for the extragalactic cosmic ray is wakefield acceleration in the extreme astrophysical conditions. Large amplitude electromagnetic (EM) waves are excited at relativistic perpendicular collisionless shocks via synchrotron maser instability [6, 7, 8, 9]. The intense EM waves propagate toward the upstream of the shock and excite wakefield due to the strong ponderomotive force of the EM waves. Numerical simulations show that the wakefields accelerate upstream electrons and also ions [6, 9], and importantly universally reproduce the power-law distribution with an index of -2 independent of plasma and EM wave conditions [10, 11]. However, there is no way to directly observe this in far distant astrophysical phenomena.

3 Model experiment

By modeling the wakefield acceleration of extragalactic cosmic rays at relativistic collisionless shocks, we have investigated the nonthermal electron acceleration with turbulent wakefield induced by relativistic laser pulses [12, 13]. The turbulent wakefields universally produce power-law electron energy spectra independent of laser and plasma conditions [12, 13]. The remaining open issue on the turbulent wakefield acceleration is whether or not the ions are accelerated. We report a numerical model of relativistic ion acceleration for the future laser experiment. We also discuss the theoretical model of supper diffusion or Levy flights using fractional Fokker-Planck equations [14].

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