Experimental demonstration of semi-relativistic magnetic reconnection by intense petawatt laser

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Magnetic reconnection is a rearrangement process of magnetic topology which is usually described as the "reconnection" of magnetic field lines. It dissipates energy as kinetic energy, in form of plasma heating and outflow plasma jets. Recently, this process is widely accepted as an important magnetic energy conversion process in a wide range of astrophysical research [1]. This process is accounted for many astronomical phenomena, such as solar flares [2], accretion disks [3] and even high-energy emission from black holes [4].

Although magnetic reconnection occurs in a wide range of astronomical plasma, there are difficulties on study depending on direct observations of magnetic reconnection in astronomical plasma. Here we introduce an experimental approach, using intense laser with pulse duration of picosecond order to produce a pair of magnetized plasma with anti-parallel magnetic geometry in laboratory. Firstly, a scheme of generating mega-ampere current by laser irradiation on a single-turn "micro-coil" was developed to generate kilo-tesla magnetic field within spatial scale in order of 0.1 mm [5].

LFEX laser, laser system with 1 ps pulse duration and 2 kJ total energy, was used to demonstrate this experimental scheme. By measuring the deflection of probe proton beam, a pair of magnetized plasma with anti-parallel magnetic geometry were observed inside the micro-coil. In terms of reconnection field strength, 2.1 kT was achieved in this experiment. Also, from the reconnection outflow direction, a pair of energetic charged particle jets are observed. By analyzing the energy distribution of the jets, non-thermal components in power-law distribution are observed in the high-energy tail of both protons and electrons. Harder power-law slope ($p \sim 1.2$) was observed in electron energy distribution, which is consistent with other simulation studies.

Further studies were performed to confirm the effect of magnetic reconnection in the particle acceleration, by introducing control case with similar magnetic field generation, in single direction instead of anti-parallel geometry. From this study, only the magnetic reconnection case showed anisotropy of electron energization, while the control case without significant magnetic reconnection showed similar electron energy distribution independent of the detection direction.

Also, by development on Thomson parabola detectors, multiple ion species are detected from the outflow jets in our further studies. We observed that every observed ion species has similar energy distribution, with scaling factor that possibly correlating with the charge and mass of the ion species. Also, the cutoff energies of ion acceleration are also related to the same scaling factor, for all heavier ion species except protons.

In the beginning, the result of hard power-law slope observed in magnetic reconnection experiment showed possibility of magnetic reconnection's contribution in high-energy emission from galactic X-ray sources, which required efficient energy conversion from magnetic energy to electron energies and having comparable physical quantities with plasma produced in this work. With our experimental results on magnetic reconnection in plasma with multi-species ion acceleration detected, we could verify different theories accounting the heavy ion detection in space magnetic reconnection systems, for example the magnetotail of planets in solar system.

References

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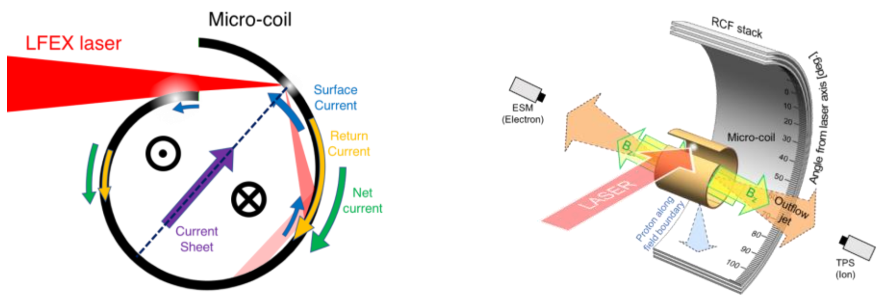

Figure 1. Mega ampere current generation by intense laser irradiation on micro-coil target (left) and the magnetic reconnection outflow detection set-up in experiment of this work.