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Laboratory observation of ion drift acceleration of laser-produced magnetized collisionless shocks

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Fermi acceleration is believed to be the primary mechanism for producing high-energy charged particles in the Universe. In this process, charged particles gain energy successively through multiple reflections. A series of experiments regarding super-critical magnetized shocks have been carried out at the Omega laser facility and the LULI laser facility [1-3]. Even so, the 'injection problem' still remains unresolved.

Here, we present direct laboratory experimental evidence of ion energization from a single reflection off a supercritical collisionless shock, an essential component of Fermi acceleration, in a laser - produced magnetized plasma. The experiments were conducted at the Shenguang II (SG II) laser facility[4]. A sketch of the experimental setup is shown in Fig. 1. A weaker precursor laser beam ($\sim 1\times10^{13}$ W/cm^2) ablated a plastic (CH_2) planar target to create the ambient plasma, which was magnetized by a 4-6 T external background magnetic field [5]. An intense drive laser beam ($\sim 8\times10^{13}$ W/cm^2) irradiated another plastic (CH_2) target with a focus spot of 0.5×0.5 mm^2 to produce supersonic plasma flow as a piston. The piston plasma flow drove a quasi-perpendicular collisionless shock in the magnetized ambient plasma. The profile of the shock and the ambient plasma density were characterized with optical diagnostics as shown in fig. 2.

A quasi-monoenergetic ion beam with a velocity two to four times that of the shock was observed as shown in fig.3 , which is consistent with the fast ion component observed in the Earth's bow shock. Our simulations reproduced the energy gain and showed that ions were accelerated mainly by the motional electric field during reflection. The results identify shock drift acceleration as the dominant ion-energization mechanism, which is consistent with satellite observations in the Earth's bow shock. Our observations pave the way for laboratory investigations of cosmic accelerators and are also beneficial to laser fusion and laser-driven ion accelerators.

References

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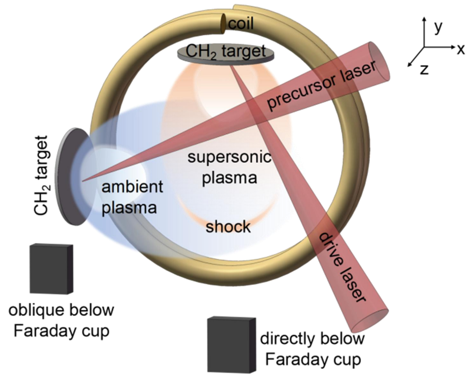

Figure 1.Sketch of the experimental setup.

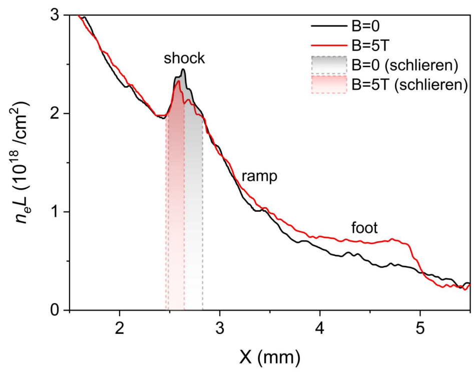

Figure 2. The line density profile from optical interferometry.

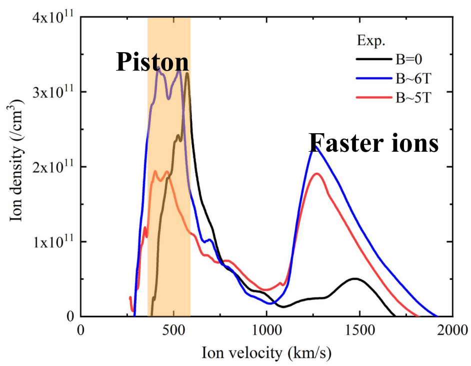

Figure 3. Ion velocity spectra in experiments