4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Experimental Observation of Ion–Ion Acoustic Instability Associated with Collisionless Shocks in Laser-produced Plasmas

J. L. Jiao[1, 2, 3], S. K. He[3], H. B. Zhuo[4], B. Qiao[1], M. Y. Yu[4], and Y. Q. Gu[3]

[1]School of Physics, Peking University, [2]College of Liberal Art and Science, National University of Defense Technology, [3]Science and Technology on Plasma Physics Laboratory, China Academy of Engineering Physics, [4]Center for Advanced Material Diagnostic Technology, Shenzhen Technology University

e-mail (speaker): jl.jiao@pku.edu.cn

Collisionless shock waves are common in space and astrophysical plasmas and are efficient particle accelerators. Micro-instabilities can be triggered during the shock formation and they can lead to particle acceleration. The ion–ion acoustic instability[1] caused by the resonance of the ion plasma oscillation of the shock upstream plasma and that of reflected ions is one of the electrostatic micro-instabilities. This instability can generate oblique ion acoustic-like electrostatic fluctuations in counter-streaming plasmas, which is different from the well-known ion acoustic instability. It has been invoked to explain several space physics phenomena, including the origin of enhanced ion acoustic line spectra in the upper ionosphere[2], the broadband electrostatic noise in the Earth's magnetotail[3].

In the context of astrophysics, numerical simulations have recently proposed that, in supernova remnants, the rapid growth of the ion–ion acoustic instability leads to turbulence in the shock upstream and damage of the shock structure[4,5]. However, such a phenomenon is difficult to verify through astronomical observations because of the remote distance and the scarcity of observable events of the supernova remnants shocks. Intense laser-plasma interaction can model astrophysical shock processes in the laboratory at much reduced scales, and provide reproducible and controllable conditions that can be used as a means of supporting astronomical observations.

We present here the experimental identification of an ion–ion acoustic instability in the expansion of a laser-heated dense plasma through a rarefied one[6]. Our experiments were performed using the XingGuang III laser facility[7,8] at the Laser Fusion Research Center in China and the setup is shown in figure 1. The dense plasma is produced from heating of a solid target by a short (2ps) intense (10^{17} Wcm^{-2}) laser pulse. The ambient plasma, where the shocks are excited and propagate, is created by the laser's nanosecond scale low-intensity pedestal. Using a proton radiograph (shown as figure 2), we monitor the shock structure and shock front filaments resulting from the electrostatic ion–ion acoustic instability. The experimental observations are in good agreement with the analytical theory of the ion–ion acoustic instability, as well as our particle-in-cell simulation results.

This work was supported by the Science Challenge Project (No. TZ2016005 and No. TZ2018005), the National Key Program of S&T Research and Development (grant No. 2016YFA0401100), the National Natural Science Foundation of China (grants Nos. 11475259, 11175253 and 11825502) and the NSAF (grant No. U1630246).

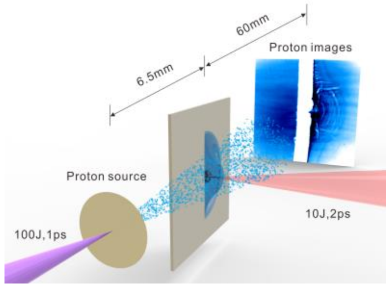

Figure 1. Experimental set-up at the XingGuang III laser facility.

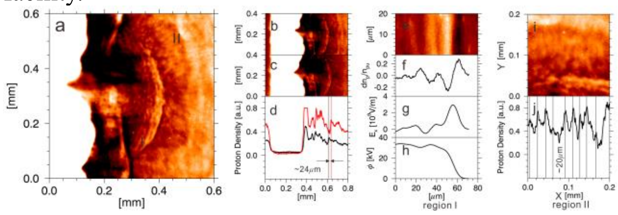

Figure 2. Proton images showing the electric field structures of the collisionless electrostatic shock and the ion-ion acoustic instability. (a), Typical proton imaging layer corresponds to a probing time of 150 ps. (b) and (c) are the proton images on different probing times (150 ps and 162 ps). (d) is the corresponding profiles of the probe proton density. (e)-(h), Details of the region I and its corresponding profile of the probe proton density perturbation, reconstructed electrostatic field and potential. (i) and (j), Details of the region II and corresponding profile of the probe proton density at Y = 0.12 mm.

References

[1] B. Fried, A. Wong, Phys. Fluid, **9**, 1084 (1966).
[2] J. Wahlund *et al*., Geo. Rev. Lett., **19**, 1919 (1992).
[3] K. Akimoto, N. Omidi, Geo. Rev. Lett., **13**, 97 (1986).
[4] Y. Ohira, F. Takahara, Astrophys. J., **688**, 320 (2008).
[5] M. E. Dieckmann *et al*., New J. Phys., **16**, 073001 (2014).
[6] J. L. Jiao *et al*., Astrophys. J. Lett. **881**, L37 (2019).
[7] S. K. He *et al*., Chin. Phys. Lett., **36**, 105201 (2019).
[8] J. L. Jiao *et al*., Acta Phys. Sin., **66**, 085201 (2017).