9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Mesoscale laser plasma physics explored by kJ petawatt lasers

Natsumi Iwata[1]

[1] Institute of Laser Engineering, The University of Osaka

e-mail: iwata.natsumi.ile@osaka-u.ac.jp

Kilo-Joule petawatt (PW) lasers enable us to study the high energy density plasma evolution with a continuous energy input by relativistic intensity light on large spatial and temporal scales on the order of 100 μm and multi-picoseconds (ps). Different from strongly focused short pulse lasers, in kJ laser plasma interactions, fluid dynamics of the plasma is coupled strongly to the kinetic laser-plasma interactions such as electron acceleration by the laser light. As a result of the multiscale interactions, enhanced particle accelerations and dense plasma heating have been observed in experiments using kJ PW lasers such as LFEX and NIF-ARC [1]. These efficient acceleration and heating are important for laser applications such as intense x-rays source, high-flux ion beam generation, and inertial fusion.

The kJ PW laser-plasma interactions belong to the mesoscale between kinetic and fluid regimes (Fig. 1) [2]. Theories for relativistic laser-plasma interactions have been developed mainly for the kinetic regime where nonthermal electrons accelerated by the laser field determine the energy absorption and transport. When the interaction time is longer than the thermal equilibration time for the laser-accelerated electrons, the hydrodynamic descriptions are applicable. In solid density plasmas, the thermal equilibration time scale is on the order of 100 ps, and therefore, the kinetic modeling is necessary. The ion collective response, characterized by the ion plasma frequency, to electromagnetic fields becomes important in the ps interactions. Furthermore, the spatial scale of ion fluid motion with the sound velocity becomes comparable to the laser wavelength of 1 μm on a ps time scale. Hence, the laser absorption mechanism changes from the sub-ps regime, which results the efficient electron and ion accelerations seen in the kJ PW laser experiments. Collisional energy transport processes in solid density plasmas, such as heat diffusion from the laser-heated plasma surface at keV temperatures, are also effective on the ps time scale [3].

This talk will provide the key physics leading to high efficiency laser-to-plasma energy coupling and energy transport in the mesoscale regime, including theoretical models for pressure balance at the laser-plasma interface, statistical phenomena for kinetic electrons, and dense plasma heating [4].

References

[1] D. Rusby *et al.*, Phys. Plasmas **31**, 040503 (2024); A. Yogo *et al.*, Sci. Rep. **7**, 42451 (2017); K. Matsuo *et al.*, Phys. Rev. Lett. **124**, 035001 (2020).

[2] N. Iwata *et al.*, Nucl. Fusion **59**, 086035 (2019)

[3] N. Higashi *et al.*, Phys. Rev. E **105**, 055202 (2022)

[4] N. Iwata *et al.*, Nat. Commun. **9**, 623 (2018); N. Iwata *et al.*, Phys. Rev. Research **3**, 023193 (2021).

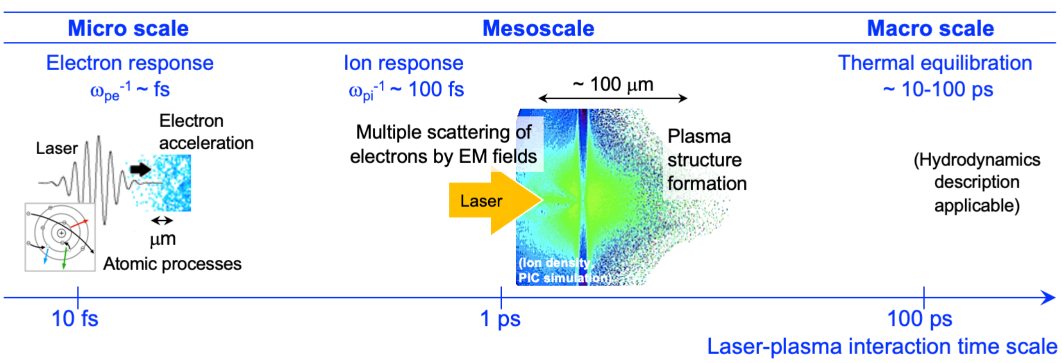

FIG. 1 Regimes of relativistic laser-plasma interaction. ω_{pe} and ω_{pi} are the electron and ion plasma frequencies, respectively, at the critical density of the laser light with the wavelength of 1 μm.