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Application of neural network in the study of the melting transition of 2D plasma crystals

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A complex plasma is a weakly ionized gas containing micron-sized dust particles. The particles are negatively charged due to the higher thermal velocities of electrons. In the laboratory, monodisperse particles are suspended in a single layer above the lower electrode where gravity is compensated by the electrostatic force in the sheath. Under certain conditions, these charged particles can self-organize in a triangular lattice with hexagonal symmetry, forming a 2D plasma crystal. Individual particle motion can be easily recorded in real time using video microscopy. This makes 2D complex plasmas excellent model systems where structure and dynamics can be studied at the level of individual particles.

The thermodynamic state of 2D complex plasma can be easily controlled by the experimental conditions. As the coupling strength decreases, the plasma crystal melts. Melting can also be induced by the localized disturbance such as shocks or shear flows driven by external field. Besides, the lateral wave of a fast-moving particle above or below the plasma crystal lattice leads to heat transport. Kinetic energy is transferred to the lattice particles via collisions with the self-propelled extra particle, resulting in the melting of the crystal lattice.

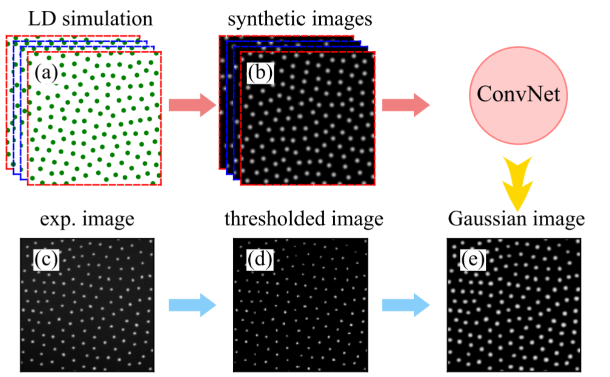

Figure 1 Scheme for applying neural network in the melting transition of 2D complex plasmas [1].

Recently, machine learning has become a powerful analysis technique in complex plasma research, such as analysis of nonlinear response, classification of crystal structure in 3D plasma crystals, and identification of the interface in binary complex plasmas. Here, we apply a convolutional neural network (ConvNet) to investigate the melting transition in 2D complex plasmas [1].

Langevin dynamics simulation is applied to prepare complex plasmas in various thermodynamic states. For the purpose of model training and later application in the analysis of experiments, sequences of images are prepared based on the simulation results. The trained model can be used to identify the thermodynamic state of complex plasma in the experiments. The scheme is illustrated in figure 1. As a result, a phase diagram is obtained, which agrees well with previous YOCP theory and numerical simulations.

We apply our trained CovnNet to two distinctive experiments to identify the state of the 2D complex plasma as it melts. In the first experiment, melting was induced by an extra particle, which moved beneath the particle layer. A sharper contrast on the identification of the melting transition is achieved than that of the traditional method based on the hexatic order parameter. In the second experiment, the melting was induced by two parallel particle flows driven by the laser beams. The spatial distribution of the liquid and crystal area is obtained.

References

[1] H Huang, V Nosenko, et al, arXiv:2204.12702