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Phase-space tomography for charge exchange recombination spectroscopy

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In order to resolve the anomalous transport problem in magnetically confined fusion plasmas, nonlinear wave-particle interaction in turbulent field has been studied [1,2]. In high-temperature and low-collision fusion plasmas, particles are trapped in a phase of a wave by which the wave potential is nonlinearly evolved and structures form in the phase-space. The phase-space structure can couple with the real space plasma profile, by which a free energy is released and the phase-space structure grows [1,2]. Stochastic overlapping and cascade of the phase-space structures are also possible, resulting in emergence of the so-called phase-space turbulence. Phase-space turbulence is considered to play a role for driving anomalous transport in high temperature plasmas, involving enigmatic transport features, e.g., nondiffusivity, nonlocality, subcriticality, and others [2]. According to those theoretical predictions, survey for possible phase-space structures and examination of their contribution on plasma transport are experimentally started [3].

One of the issues that make phase-space structure measurement challenging is the trade-off relationship among time, real-space, and velocity-space resolutions and signal intensity. As the total signal intensity that is determined by the diagnostic system and plasma condition is constant, improving resolution results in a decrease of signal intensity at a single detector pixel [3]. By performing a space-integration (by compromising the spatial resolution), ultrafast measurement of the plasma ion velocity distribution function was successfully performed recently [4].

Recently, a new signal processing algorithm is proposed to overcome the trade-off relationship among resolutions and signal intensity, that is, the phase-space tomography. In this algorithm, a set of three integrated signals with the same viewing sight is used to recover the three-dimensional resolution in the phase-space, i.e., the space spanned by time, real-space, and velocity-space coordinates. Integrations are performed in each of dimensions, i.e., time, real-space, and velocity-space. Schematic view of this algorithm is shown in Fig. 1. As the tomography technique, the maximum likelihood expectation maximization (MLEM) method is used.

This concept is applied to a test data created according to the Large Helical Device (LHD) observation [4]. The target physics is the energetic-particle driven magnetohydrodynamic (MHD) burst events. After the MHD burst, the Landau damping is observed, which induces the non-Maxwellian distortion of the velocity distribution function. In [4], the spatially integrated measurement with a high time-resolution was performed. The main diagnostic system used for the velocity distribution function measurement is the charge exchange recombination spectroscopy (CXS). By combining the ultrafast CXS [4] with the conventional CXS and the ultrafast line-emission measurement, the dataset for the phase-space tomography is composed: they correspond to the real-space integrated data, the time integrated data, and the velocity-space integrated data, respectively. Diagnostic simulations for those systems are performed and three integration data are made from the test data having full three-dimensional resolution. By use of the MLEM algorithm, the original test data is successfully recovered. For the actual use, robustness against the realistic noise is also examined, and a reasonable robustness is found.

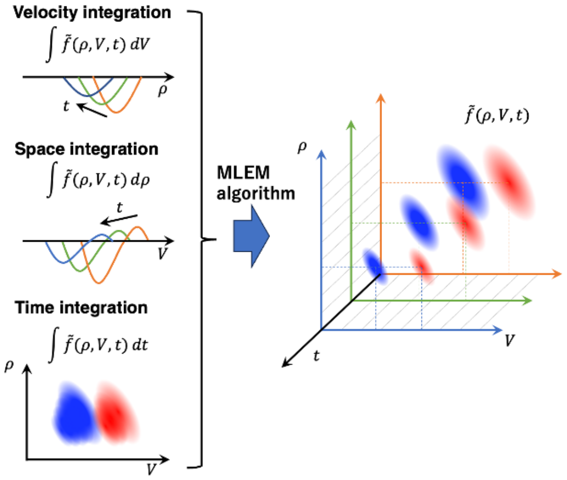

Fig. 1. Schematic of phase-space tomography.

References

[1] P. W. Terry, P. H. Diamond, and T. S. Hahm, Phys. Fluids B **2**, 2048–2063 (1990)
[2] Y. Kosuga, S.-I. Itoh, P. H. Diamond, K. Itoh, and M. Lesur, Nucl. Fusion **57**, 072006 (2017)
[3] T. Kobayashi, Plasma Fusion Res. **18**, 2402059 (2023)
[4] K. Ida, T. Kobayashi, M. Yoshinuma, et al., Commun. Phys. **5**, 228 (2022)
[5] T. Kobayashi, M. Yoshinuma, W. Hu and K. Ida, Phys. Plasmas **30**, 052303 (2023)