

Synergetic Complexity and structure formation of plasmas dominated by atomic and relaxation process

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The interaction between laser fields and various material states leads to a complex plasma state, where multiply charged ions and free electrons, polarized atoms and molecules, induced fields with different frequencies coexist. Such plasmas exhibit the characteristics as active medium, which is highly non-equilibrium and non-steady state with strong spatial inhomogeneity. Such complex states are seen not only in laboratory plasmas, but also in nature plasmas, such as aurora, lightning and discharge plasma, solar flare, inter-stellar medium, etc. Some of those have been studied, but the details have not been clarified due to its complexity.

In order to investigate such complex plasma states, we have developed an integrated code (EPIC3D) based on the PIC technique, which is superior for describing meso-scale linear and nonlinear plasma dynamics, but extending the model by including various microscopic processes in Debye length such as polarization, ionization, recombination, collisional relaxation, etc [1].

Based on the code, we performed the simulation of discharge/lightning process of compressed neon gas and reproduced streamer formations and successive prominent discharge events [1]. We have seen that enormous branches with different spatial scales which is referred as sprite is observed. Electromagnetic radiations are found to be emitted from such complex net-like structures. From the analysis of emitted radiations, we found a clear power law spectrum is found, suggesting that the sprite shows a fractal nature. It is interesting to note that similar spectra have been observed in low frequency electromagnetic signals during lightning events in the atmosphere. We also applied the code in studying the interaction of ultra-short high power lasers with solid targets and clustered materials [2]. A tight coupling between ionization and associated energy transport is found to play an essential role, leading to new interaction dynamics and structure formation. Avalanche-like propagation of the ionization front triggered by the Cherenkov turbulence, non-local heat transport accompanied by the ionization and plasma production, non-local ionization events leading to a sudden event.

The above prominent plasma dynamics results from a synergetic interplay between macro-scale plasma dynamics of collisionless ideal plasma and micro-scale dynamics inside Debye sphere such as atomic and molecular process as well as collisional relaxation process.

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[2] T. Masaki and Y. Kishimoto, Multi-stage ionization dynamics of carbon film irradiate high power lasers, Journal of Plasma and Fusion Research, 81, No.10, 643-644 (2005)