§17. Summarizing IAEA-Technical Meeting on Theory of Plasma Instabilities

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The 4th IAEA technical meeting (IAEA-TM) has been designed being motivated by the recent advancement in theoretical methodology, by the rapid progress in observations of laboratory and astrophysical plasmas, and by the evolution of fusion research of ITER era. This IAEA-TM provides a forum for discussion on theoretical and computational physics issues relevant to burning plasma. Special attention is paid to the physics of nonlinear and nonequilibrium systems, the multi-scale interaction dynamics in plasmas and to the modeling of such complex physical processes. Excited discussions were realized on talks and posters.

This work summarizes scientific presentations in the TM, reporting key progresses in theory and simulations of plasma instabilities and related physics [1,2]. In this TM, the summary was made by one person. This caused limitations in complete description of full merits of all presentations (which are more than 70). However, on the expense of this limitation, a more coherent description for the mutual relations among various works could be possible. Taking this standpoint, this review is focused in accelerating the tide that '*knowledge must be developed into understanding*'. In realizing this evolution, integration of the theory, simulation and experiments is crucial, and an emphasis is made on it as a key for the future progress. Reference is limited by two reasons: First, many presentations in the TM report the ongoing research frontier. Second, this summary covers the issues presented in the TM and cannot cover all of theory of plasma instabilities. In order to make presented work more easily accessible for readers, a few relevant references to presentations are supplemented. For the connection to wider field of theory of plasma instabilities, readers are referred to reviews, which guide to abundant original articles.

View point of this summary is as follows.

Theoretical and computational researches could address the physics of plasma instabilities from various viewpoints. In this summary, a viewpoint is chosen in characterizing the subjects of the research as:
(1) System of equations
(2) Study of elementary process associated with instabilities
(3) Deduction of microscopic as well as macroscopic dynamics
(4) Prediction of experiments
(5) Test and validation with experimental observation
(6) Inductive study to define problems associated with experimental mystery.

After the long history of theory and simulation studies, the recent progress has been noticeable in the realm of understanding synthetic dynamics. Based on this fact. I would choose the key concepts in this summary that the way of thinking has evolved

From '*linear, local and deterministic*' models
To '*nonlinear, nonlocal, statistical*' models.

For instance, according to the conventional view, the anomalous transport has been described by the diffusivity $\chi_{\text{conventional}} = \gamma_L k_\perp^{-2}$, where γ_L and $k_\perp$ are the linear growth rate and wave number, respectively, of the most unstable mode at local position [3]. This model captures an essential element in instability and turbulence. However, such a model has been understood unsatisfactory (See, for review, e.g., [4-7]). How this (linear, local and deterministic) old view has been (and will be) modified is explained in this summary.

The following issues are explained in detail:
Key elements in zonal flow physics,
Importance of stable mesoscopic/macroscopic modes,
Micro and hyper micro fluctuations,
Nonequilibrium property of plasma turbulence,
Non-diffusive transport,
Nonlocal transport,
Evolution of islands,
Dynamics of islands in the presence of turbulence,
MHD instability,
Energetic particles and instabilities,
Integrated code and prediction of synthetic dynamics, and
Experimental test and validation.
Adding comments on research structure, this summary closes by highlighting future challenges.

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