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Comparing Turbulence Measurements with Simulations: an Experimental, Multi-Machine Tutorial on Validation of Nonlinear Gyrokinetic Transport Models

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Tokamaks and stellarators are used to confine and control plasmas for fusion energy research. Understanding heat, particle and momentum transport and the development of validated predictive transport models is critical for ITER operations and for design of other burning plasma devices. Validation of transport models, and especially of nonlinear gyrokinetic simulations, requires close coupling between experiment, computation, and theory. Recent advances in measurement capabilities at ASDEX Upgrade, C-Mod, DIII-D, JET, MAST, NSTX, TCV, W7-X and other fusion devices around the world, have opened the door to unprecedented, highly detailed, comparisons between experiments and nonlinear gyrokinetic simulations. This talk will explore the distinction between "comparing measurements to a simulation" and "validating a transport model". Synthetic diagnostics, models that mimic the spatial (or wavenumber) response of the turbulence measurements [1] and new international thrusts toward predictive experimental design [2] using nonlinear gyrokinetic simulations will be discussed, along with the role of reduced models (e.g. QuaLiKiz and TGLF) and prospects for machine-learning methods [3]. Open questions regarding multi-scale turbulence physics [4,5,6] and the challenges surrounding validation of nonlinear multi-scale gyrokinetic simulations will be assessed. Overall, this tutorial talk will explore both the history and present state of "comparison" and "validation" activities, from an experimental and cross-machine perspective.

References

[1] C. Holland et al. Implementation and application of two synthetic diagnostics for validating simulations of core tokamak turbulence, Phys. Plasmas, 16, 052301 (2009)
[2] S. Freethy et al. "The role of theoretical predictions in the design of correlation ECE and nT-phase diagnostics", invited talk, 21st EU-US Transport Task Force Meeting, Leysin, 5-8 September 2016
[3] J. Citrin et al. "Circumventing the conflicting constraints of speed and accuracy for tokamak turbulence modeling", invited talk, 21st EU-US Transport Task Force Meeting, Leysin, 5-8 September 2016
[4] T. Goerler and F. Jenko "Scale Separation between Electron and Ion Thermal Transport" Phys. Rev. Lett. 100, 185002 (2008)
[5] N. T. Howard et al. "Synergistic cross-scale coupling of turbulence in a tokamak plasma" Physics of Plasmas 21, 112510 (2016)
[6] S. Maeyama et al. "Cross-Scale Interactions between Electron and Ion Scale Turbulence in a Tokamak Plasma" Phys. Rev. Lett. 114, 255002 (2015)