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On the validity of scale invariance and power laws for describing and predicting confined plasmas

J. Garcia and JET contributors*

CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France

*See the author list of "Overview of the JET preparation for Deuterium-Tritium Operation" by E. Joffrin et al. to be published in Nuclear Fusion Special issue: overview and summary reports from the 27th IAEA FEC (Ahmedabad, India, 22-27 October 2018)

e-mail:jeronimo.garcia@cea.fr

Scale invariance is a powerful technique used to analyze dynamical physical systems. In the case of plasmas, if the equations governing the behavior are assumed to be known, then the technique of scale invariance can be used to derive the necessary dimensionless relationships between the variables that appear in the equations. When applying such techniques to the Vlasov equation, a few dimensionless variables, which in principle should fully describe the plasma, are obtained. The transformation of such variables to dimensional ones is straightforward.

In order to ensure scale-invariance, power laws are the first mathematical approach used. However, significant deviations from well established power laws for the thermal energy confinement time of magnetic confinement plasmas, obtained from extensive databases analysis, have been recently reported in dedicated power scans [1]. In order to illuminate the adequacy, validity and universality of power laws as tools for predicting plasma performance, an analysis has been carried out in the framework of a minimal modeling for heat transport that is, however, able to account for the reduction of turbulence by collinear effects with the input power (such as increased fast ion fraction which reduces turbulence in the thermal ions larmor radius scale [2]). The heat transport equation is solved showing that at low powers, well-known power laws are recovered with little influence of other plasma parameters, resulting in a robust power low exponent. However, at high power it is shown that no universal exponent can be obtained due to the strong non-linear behavior of the plasma and its dependence on multiple plasmas variables such as the magnetic shear or the heating location. In particular circumstances, even a minimum of the thermal energy confinement time with the input power can be obtained, which means that the approach of the energy confinement time as a power law might be intrinsically invalid [3]. As a result, turbulence might not be scale invariant in a confined plasma, as already suggested by multi-scale gyrokinetic simulations [4].

References

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