A statistical approach to strange diffusion phenomena

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The study of particle (and heat) transport in fusion plasmas has revealed the existence of what might be called "unusual" transport phenomena. Such phenomena are: unexpected scaling of the confinement time with system size, power degradation (i.e. sub-linear scaling of energy content with power input), profile stiffness (also known as profile consistency), rapid transient transport phenomena such as cold and heat pulses (travelling much faster than the diffusive timescale would allow), non-local behaviour and central profile peaking during off-axis heating, associated with unexplained inward pinches. The standard modelling framework, essentially equal to Fick's Law plus extensions, has great difficulty in providing an all-encompassing and satisfactory explanation of all these phenomena.

This difficulty has motivated us to reconsider the basics of the modelling of diffusive phenomena. Diffusion is based on the well-known random walk. The random walk is captured in all its generality in the Continuous Time Random Walk (CTRW) formalism. The CTRW formalism is directly related to the well-known Generalized Master Equation, which describes the behaviour of tracer particle diffusion on a very fundamental level, and from which the phenomenological Fick's Law can be derived under some specific assumptions. We show that these assumptions are not necessarily satisfied under fusion plasma conditions, in which case other equations (such as the Fokker-Planck diffusion law or the Master Equation itself) provide a better description of the phenomena. This fact may explain part of the observed "strange" phenomena (namely, the inward pinch)[1,2].

To show how the remaining phenomena mentioned above may perhaps find an explanation in the proposed alternative modelling framework, we have designed a toy model[3,4] that incorporates a critical gradient mechanism, switching between rapid (super-diffusive) and normal diffusive transport as a function of the local gradient[5,6]. It is then demonstrated that this toy model, characterized by both criticality and non-locality, indeed produces the cited phenomena in a natural fashion.

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