A simplified model for anomalous transport in fusion plasmas

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Thermonuclear fusion plasmas constitute open systems that are far from equilibrium due to strong externally imposed drives (heating and particle fuelling), creating very steep gradients of temperature and density. Such gradients are required to attain the high temperature and density conditions required to sustain fusion reactions in the core of the system.

Not surprisingly, transport in these systems is anomalous. Some estimates indicate that transport fluxes may, under some circumstances, exceed the predicted "neoclassical" fluxes by about an order of magnitude. Detailed experimental studies of the behaviour of transport in these systems have revealed behaviour that differs strongly from a diffusive system: (a) at high power, the confinement time decreases, indicating increased losses ("power degradation"); (b) the transport coefficients (diffusivities) depend on the system size, suggesting that the transport lacks a characteristic scale; (c) profiles are "stiff", i.e. relatively insensitive to the sources; (d) transport may locally be directed "up the gradient"; and (e) the propagation of perturbations is, under some circumstances, extremely rapid, suggesting some degree of non-locality – it may even happen that perturbations change sign while propagating. Taken together, this phenomenology implies that the standard approach to transport, using diffusive equations with smooth dependencies of the transport coefficients on the local system parameters, may be inadequate.

To come to terms with these issues, we have turned to the Continuous Time Random Walk, generalised appropriately to handle the presence of a critical gradient mechanism [1-5]. In fusion transport studies, it is generally accepted that such mechanisms, in which an instability is triggered when a gradient (of e.g. pressure) is exceeded locally, are operative. This instability then causes locally enhanced transport. Ample experimental support for this assumption is available. To capture the non-local aspect of anomalous transport, we model supercritical transport using Lévy distributions.

The numerical time evolution of the corresponding Generalized Master Equation is shown to reproduce the phenomenology summarised in the five points above. We present a summary of the numerical results, and discuss the difficulty of distinguishing the transport effects of the critical gradient mechanism from the effects caused by using Lévy distributions.

References

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