Transport in Nuclear Fusion plasmas: from Self Organized Criticality systems to Magnetohydrodynamics

Javier H. Nicolau[1], Luis García[1] and Benjamín Carreras [1,2]

[1] Universidad Carlos III, 28911 Leganés, Madrid, Spain
[2] BACV Solutions, 110 Mohawk Road, Oak Ridge, Tennessee 37830, USA

Magnetically Confined Nuclear Fusion has become the most promising candidate to control and efficiently obtain fusion energy. Particles are in a plasma state and, the magnetic fields confine and compress the plasma in a toroidal geometry to reach extreme temperatures in the core which generate the nuclear reactions. A better understanding of the radial transport is fundamental to control the confinement and losses in the plasma.

Experiments in Nuclear Fusion devices show, for example, system size scaling or superdiffusive propagation which could not be explained by the classical diffusion equations. It has been called *anomalous transport*. Those effects reduce the confinement and increase the losses in the plasma. However, at certain conditions, the plasma rotates at different speeds creating a shear in the radial direction. That shear flow creates a transport barrier which reduces the anomalous effects.

A Self-Organized Critical (SOC) system could describe qualitatively some of the anomalous effects [1]. And a simply introduction of a transport barrier could reduce those effects. A schematic of a 2D sandpile (the generalization of a SOC system) with shear flow is shown in Fig. 1.

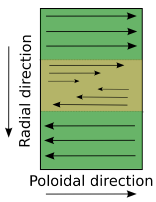

Figure 1: Schematic of a SOC system with shear flow.

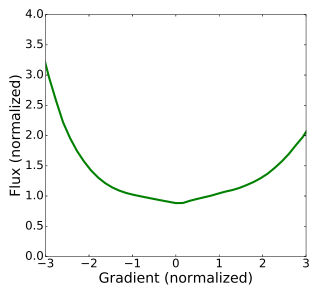

Figure 2: Normalized gradient and flux in a fixed position.

The transport in a sandpile is driven by avalanches (generated by critical gradients) inside the system. The avalanches are scale free and are only limited by the system size. Furthermore, a high Hurst exponent indicates superdiffusive behavior in SOC systems [2] as has been measured experimentally [3].

The discrete sandpile model can be extrapolated to a continuous system. The model is described by a one dimensional diffusion equation which diffusivity is controlled by a critical-gradient equation [4]. The model has the properties of a SOC system as a high Hurst exponent value [5]. Non-local effects in the transport are driven by the avalanches. The gradient-flux relation exhibits a parabola-like curve (see Fig. 2) which has been observed in fusion devices [6].

On the other hand, turbulence induced transport can be modeled by Magnetohydrodynamics (MHD) which has been shown it has SOC properties [7]. In our resistive MHD model, the instabilities in the plasma are driven by pressure gradients. A heat perturbation is introduced in a inner region in the plasma. The left panel on Fig. 3 shows the shear flow generated in the plasma before the perturbation. The right panel illustrates the temporal evolution of the heat perturbation inside the plasma. The horizontal dashed lines indicates the location of the local maxima and minima of the shear flow. The heat perturbation propagates radially but it is slowed down by the shear flow in the system. This behaviour cannot be explained by a pure diffusive model.

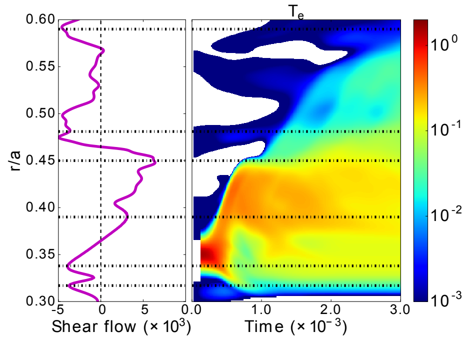

Figure 3: The left panel shows the shear flow at the initial time. Right panel illustrates the time evolution of the heat perturbation.

Similar radial propagation and slowdown has been recently observed using the Transfer Entropy method. The technique has been applied in fusion plasmas to measure the causal relation between signals.[8]

[1] Newman D E, Carreras B A, Diamond P H and Hahm T S. Phys. Plasmas **3**, 1858, (1996).

[2] Woodard R, Newman D E, Sánchez R and Carreras B A. Physica A **373**, 215 (2007).

[3] Carreras B A, van Milligen B P, Pedrosa M A and Balbin R. Phys.Rev. Lett. **80**, 4438 (1998).

[4] García L, Carreras B A and Newman D E. Phys. Plasmas **9**, 841 (2002)

[5] Nicolau J H, García L and Carreras B A. J. Phys.: Conf. Ser. **775**, 012008 (2016).

[6] Hidalgo C, Silva C, Carreras B A, van Milligen B Ph, Figueiredo H, Garcia L, Pedrosa M A, Gonçalves B and Alonso A. Phys. Rev. Lett. **108** 065001 (2012).

[7] Carreras B A, Newman D, Lynch V E, Diamond P H, Physics of Plasmas **3**, (8), 2903-2911 (1996).

[8] van Milligen B Ph, Nicolau J H, García L, Carreras B A and Hidalgo C. (submitted) arXiv:1701.04574 (2017)