Dynamical relation between gradients and transport in Fusion Plasmas

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1-Introduction

Understanding the dynamical relation between transport and gradients is an unsolved problem in Fusion Plasmas. Turbulent transport is governed by instabilities at any scale that connect different regions of Plasma. Moreover, a nonlinear relation between gradients and fluxes has been experimentally observed. We plan to develop a model to describe the transport inside the confined plasma. Our first approach is a unidimensional model based on a SOC system.

2-Experimental background

Recently, observations done in the stellarator TJ-II (CIEMAT) and in other devices show a surprising relation between gradient and flux as can be seen in the figure. Data reveals that for gradient (X-axis) higher than mean value, higher fluxes (Y-axis) are produced as one can expect. However for lower values of gradient, the flux also increases.

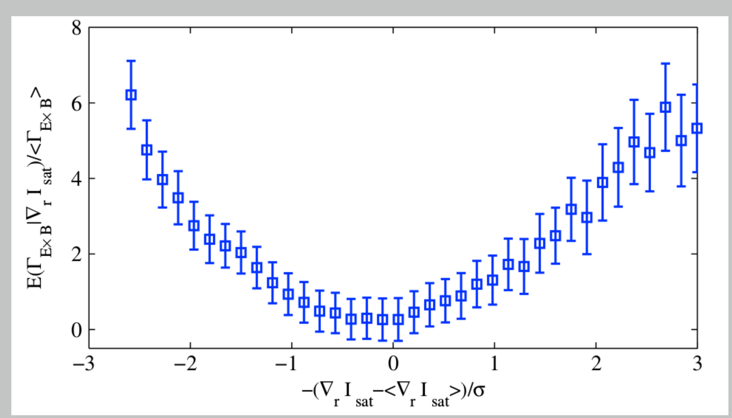

Figure 1 : **Normalized gradient(X-axis) and flux(Y-axis) from experimental data from TJ-II [1]**

3-SOC system

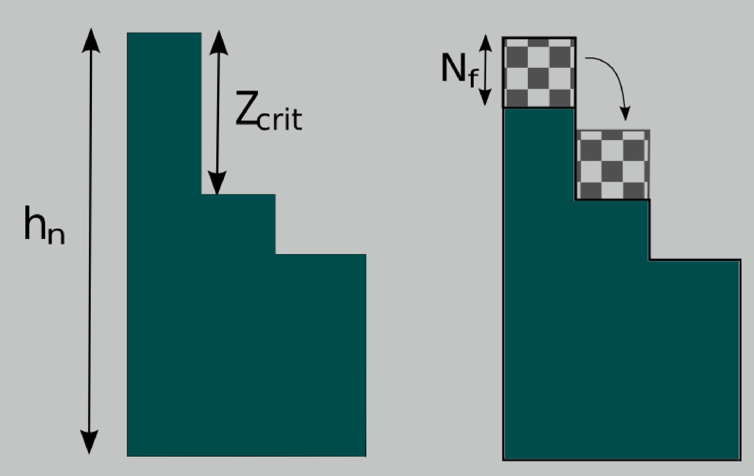

Figure 4 : **Schematic of the sandpile rules.**

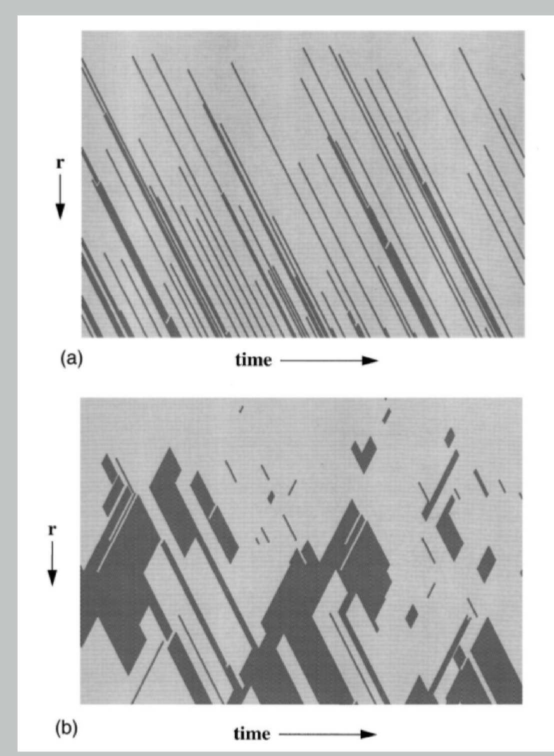

Figure 5 : **Transport in marginal(a) and submarginal(b) profiles.[2]**

Self-Organized Criticality (SOC) systems have been presented as a paradigm of anomalous transport in confined Fusion Plasmas. These systems emerge as a collective behaviour in diverse areas as earthquakes, blackouts... The most simple case is a 1D sandpile which is schematically shown in Fig.4. We randomly add grains and as soon as the grains exceeds a critical gradient z_c an amount of sand N_f is displaced to the next cell. No matter how we began, the system will evolve (*self-organized*) to a slope close to z_c (*criticality*). This is the so-called *marginal state*. The transport in the marginal case is showed in Fig.5(a), new grains fall down to the end of the pile. However, for higher dimensions or more complicated models the transport can be different as in Fig.5(b) where we can see "avalanches". They are ruled by power laws and can be of any size. In that case, the system is close to a *submarginal* region with a lower gradient.

4-Model

Here we study a one dimensional transport model based on critical-gradient fluctuations dynamics[3] . It has the properties of a SOC system.We make an analogy from the height h of a sandpile to the particle density in the plasma. The transport is regulated by fluctuations with this two coupled equations

$$\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(\mu_0 \phi \frac{\partial h}{\partial x}\right) + S_0, \qquad (1)$$

$$\frac{\partial \phi}{\partial t} = \phi\left(\gamma - \mu\phi\right) + S_1. \qquad (2)$$

The Eq.1 is a transport equation with a radial diffusion term and a source term S_0. The diffusivity is proportional to $\mu_0\Phi$ where $\Phi(x)$ are the fluctuations who are controlled by Eq.2. Coefficient γ is a critical-gradient instability

$$\gamma = \gamma_0\left(-\frac{\partial h}{\partial x} - z_c\right)\Theta\left(-\frac{\partial h}{\partial x} - z_c\right).$$

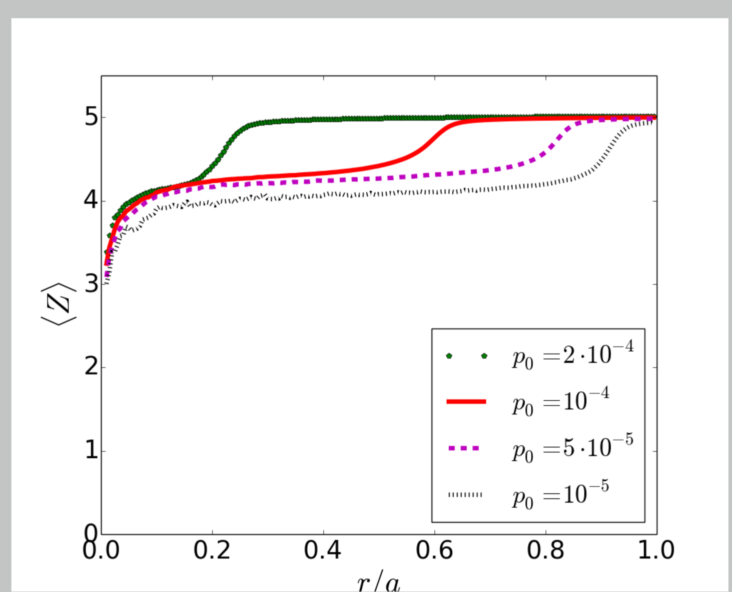

Figure 2 : **Average slope of the profile.**

The profile has clearly two regions. The outer region is close to the marginal state and the flux is continuous as in Fig.5(a). The core region remains at a submarginal state with bursty fluxes as in Fig.5(b). The transition point is tuned by p_0, the probability to add new grains.

5-Gradient and transport in the model

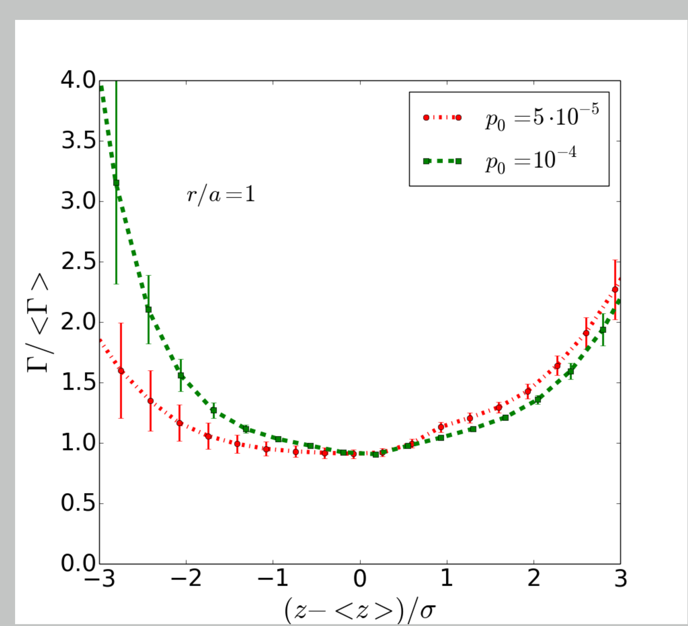

Figure 6 : **Normalized gradient and flux.**

Simulations suggest a relation between gradient and flux similar at the experimental results presented before. The figure 6 shows results at the edge of the profile for different p_0. We expcected that the nonlocal effects (present in our model) were the reason of the behaviour.

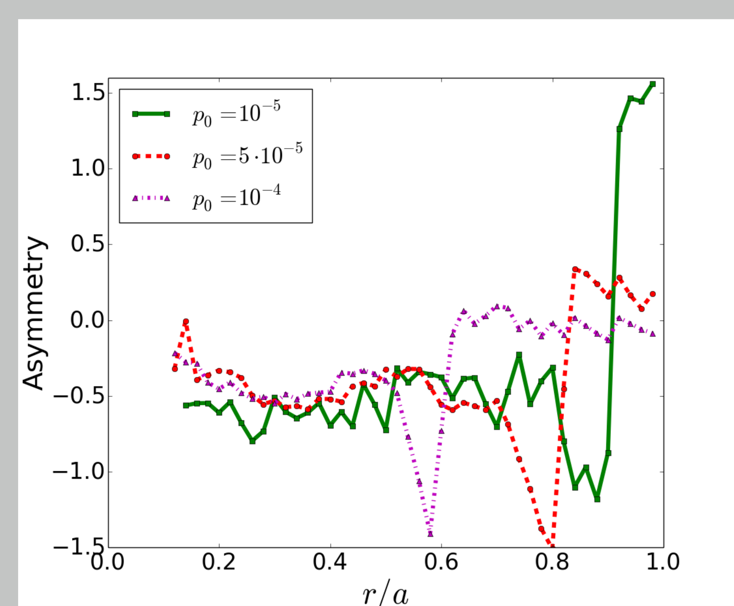

Figure 7 : **Symmetry for different p_0 as a function of radius.**

Figure 7 shows the symmetry of the gradient flux relation as a function of radial position. We can see clearly two different regions and a discontinuity caused by the transition between marginal and subcritical region.

6-Hurst exponent

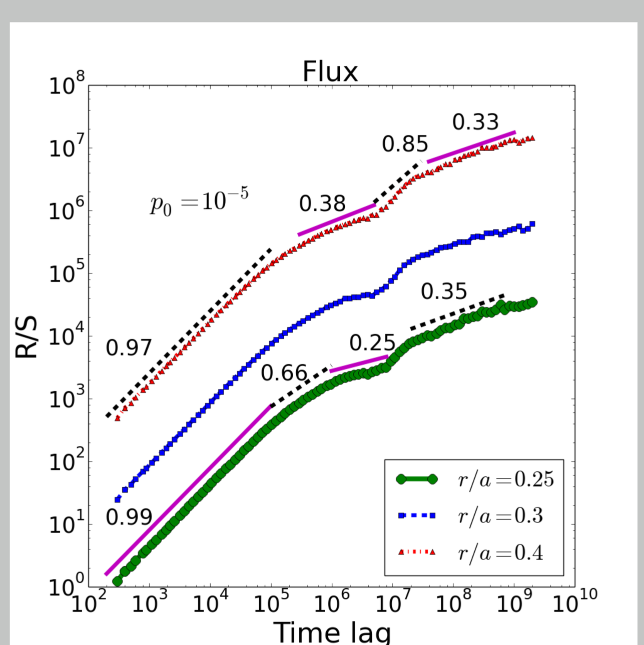

Figure 3 : **RS and Hurst exponents.**

We are calculating the correlations of the flux in the model through the hurst exponent.

$H > 0.5 \rightarrow$ Correlation

$H < 0.5 \rightarrow$ Anticorrelation

$H = 0.5 \rightarrow$ Random signal

Figure 3 shows that our system has correlations for long times. This is a common property of SOC systems and it has been observed in fusion plasmas.

7-Other work: 2D sheared sandpile model with blobs

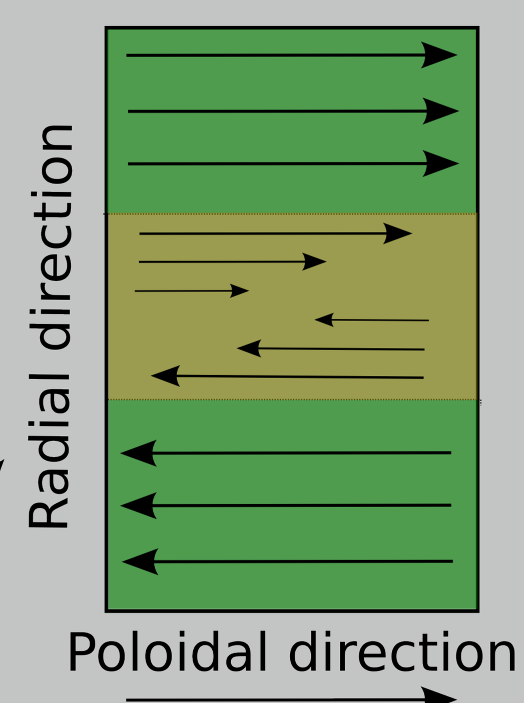

Figure 8 : **2D sandpile with shear flow.**

The model is a 2D SOC system with shear flow. The flow at the top and the bottom is constant, but in the middle there is a sheared region. Grains of sand are falling down the pile in the radial direction but they are shifted due the shear flow.

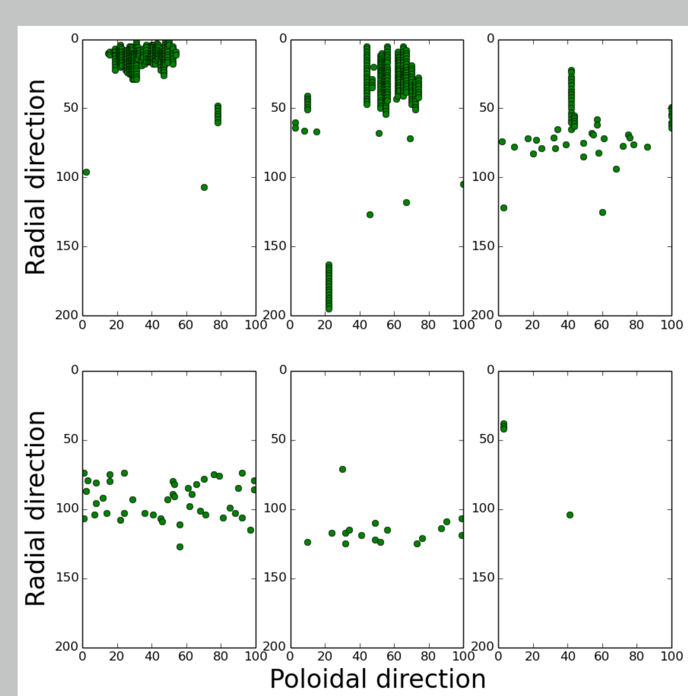

Figure 9 : **Evolution of a blob.**

We throw blobs at the sandpile. The blob creates large avalanches but once they enter in the shear region they are decorrelated. We are currently calculating the Hurst exponent.

References

[1] C.Hidalgo, C.Silva, B.A.Carreras, B.van Milligen, H.Figueiredo, L.Garcia, M.A.Pedrosa, B.Gonçalves and A.Alonso. *Dynamical coupling between gradients and Transport in Fusion Plasmas.* Physical Review Letters,**108**, 065001 (2012)

[2] D.E. Newman, B.A.Carreras, P.H.Diamond, T.S Hahm. *The dynamics of marginality and self-organized criticality as a paradigm for turbulent transport.* Physics of Plasmas,**3**, 1858 (1996)

[3] L.Garcia, B.A.Carreras, D.E. Newman. *A self-organized critical transport model based on critical-gradient fluctuation dynamics.* Physics of Plasmas,**9**, 841 (2002)

[4] B.A. Carreras, B.P.van Milligen, M.A.Pedrosa, R.Balbin. *Long-Range Time Correlations in Plasma Edge Turbulence.* Physical Review Letters **80**, 4438. (1998)

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