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Nonlocal transport in toroidal confinement devices

Gianluca Spizzo[1] and Roscoe B. White[2]
[1] Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA), Padova, Italy
[2] Princeton Plasma Physics Laboratory, Princeton, NJ (USA)
e-mail (speaker):gianluca.spizzo@igi.cnr.it

Collisional particle transport in the presence of field perturbations originating from various kinds of MHD activity is examined theoretically on tokamaks (ITER, ASDEX Upgrade, NSTX and DIII-D) and the reversed-field pinch RFX-mod [1]. For ITER and ASDEX Upgrade, modes that typically leading to a disruption are considered. On NSTX and DIII-D unstable Alfvén modes are investigated. Finally on RFX-mode the effect of saturated tearing modes is studied.

It is well-known that transport is not always diffusive in situations involving stochastic magnetic fields [2]. This fact is related to the Kubo number, which is defined as

$$K = \frac{\delta B}{B}\frac{L_\parallel}{L_\perp} \quad , \qquad (1)$$

where $L_\parallel$ and $L_\perp$ are the parallel and perpendicular correlation lengths, respectively. For 0.3 < K < 1, it is shown that the diffusion coefficient D follows the quasilinear scaling $D \approx K^2 L_\perp^2/L_\parallel$, and the system shows a diffusive behavior, with $\langle (x(t)-x(0))^2 \rangle = 2Dt$. But what happens in typical experimental situations with a *real stochastic field* in a fusion device? The answer is not straightforward: for example, the evaluation made in the RFX reversed-field pinch in Padova, Italy, shows K ~ 1.5 for a typical tearing mode spectrum, but can vary in between this value and K =10, depending on perturbation amplitude [3]. Values of K>1 imply a deviation from diffusion, $\langle (x(t)-x(0))^2 \rangle = 2Dt^p$, with either p>1 (superdiffusion) or p<1 (subdiffusion) [2]. Moreover, the determination of $L_\parallel$ is questionable in a system with finite size, as e.g. a real fusion device with MHD modes with a global nature.

In this talk, instead of looking at general features of chaos, we will examine ion and electron realistic motion in a stochastic magnetic field in fusion devices, in presence of Lorentz collisions, with the Hamiltonian guiding center code Orbit [4].

The existence of subdiffusive transport (p=0.5) for electrons is found to occur in some scenarios at very low mode amplitudes, such as ITER in a pre-disruptive phase. Subdiffusion is also found for ions of high energy, in the same ITER run. In fact, orbit resonances can produce long time correlations and dynamical traps for particle trajectories (the so-called *cantori*) at perturbation amplitudes much too small for the orbits to be represented as uniformly chaotic. The presence of these cantori has been recently well diagnosed in the RFP [5]. Besides this, in all devices orbits show a high degree of anisotropy, especially when comparing the angular (toroidal and poloidal) and radial directions. As a consequence, the use of a traditional diffusive-convective scheme for transport, leading to the well-known transport scalings, is questionable [6]. The existence and nature of subdiffusive transport is found to depend on the nature of the mode spectrum and frequency as well as the mode amplitudes [1]. The connection between subdiffusive transport and nonlocal models of transport, such as the Montroll equation [3], is also discussed.

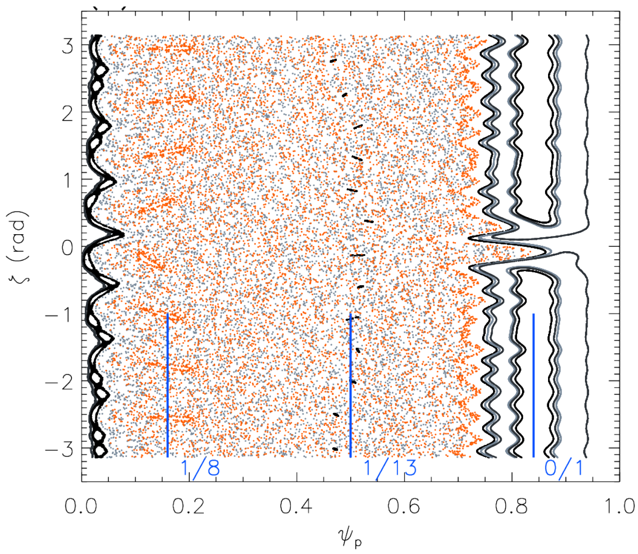

Figure 1: example of Poincaré plot in the chaotic state of the RFX reversed-field pinch in Padova, Italy: marked in blue are the chain of islands, *m/n*=1/8, 1/13 and 0/1, which act as dynamical traps, determining particle subdiffusion with exponent p~0.5

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