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Intermittency in plasmas

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Abstract

In this work we study intermittency in plasmas by the analysis of two different experimental measurements of magnetic field: the solar wind data from the Helios2 spacecraft (SW), and the data from the Reversed Field Pinch eXperiment (RFX) in Padova, Italy. To do that, we perform a wavelets analysis, which lead us to a separation of the field in two components, that is the gaussian background and the intermittent structures. The statistics of the structure distribution is also studied.

Intermittency is one of the most important features of plasma turbulence [1, 2]. The equations of the magnetohydrodynamic, as well as in the case of fluids, display scale invariance, which lead to a self–affine behavior of the fields. As a consequence, the Probability Distribution Functions (PDFs) of the fields fluctuations are not gaussian but depends on the scale. The smaller the scale, the higher the tails of the PDFs. This can be seen as the effect of the formation of "structures" in which the turbulent activity is concentrated, representing the strong events in the tails of the PDFs. The wavelets analysis has been shown to be an important tool to study the statistical properties of turbulence when intermittency is present [3]. In fact, it leads to the separate analysis of the turbulent structures at different scales. In this work we use a method recentely developed to extract such structures in order to get informations about their statistics [4].

We analyse two different experimental datasets in order to compare different plasma situations. The first one is solar wind, the only natural laboratory for plasma physics. We use the magnetic field measurements of the solar wind (SW) taken by the Helios2 spacecraft in 1976 in the interplanetary space between $1AU$ and $0.3AU$ /citesorriso. The different physical situation between the fast and the slow wind suggest to perform a separate analysis. Our dataset consists thus of two samples, each one of about 10^4 points. The second experimental situation is a laboratory plasma. We study the magnetic field inside the Reversed Field Pinch eXperiment (RFX) in Padova, Italy /citecarbone. Different behaviour is found at different positions with respect to the wall of the plasma chamber, so we will analyse separately the different datasets. The sample size is again of about 10^4 points.

The first step is to compute the wavelets coefficients of the time series. It can be shown that the statistical properties of the wavelets coefficients of a given time scale recover those of the field differences computed at the same time scale, namely:

$\delta b_\tau(t) = b(t+\tau) - b(t)$. So, the classical analysis of the structure function scaling exponents and of the PDFs can be performed using the wavelet coefficients instead of the fields fluctuations. In figure we present the PDFs of the normalized wavelet coefficients of the solar wind magnetic field. As can be easyly seen, the PDF is a gaussian at large scale, but the tais of the distribution become higher as the scale decrease, up to the saturation in the dissipation range, where the non-linear transfer of energy is cutted off. Similar results hold in the case of the RFX plasma.

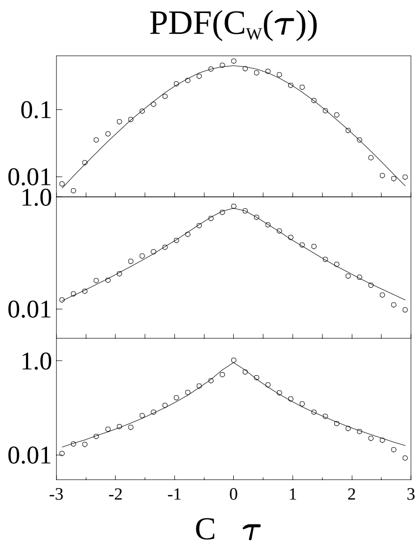

Figure 1. *The PDFs of the normalized wavelet coefficients of the magnetic field at different scales (from the top: $\tau = 12min$, $\tau = 55min$ and $\tau = 1day$). The solid line represnt a fit with a multifractal model [5].*

To have a more quantitative measure of the departure from gaussianity, we computed the flatess: $F = \langle W(t,\tau)^4 \rangle / \langle W(t,\tau)^2 \rangle^2$, that is the fourth–order moment of the PDFs. In the gaussian case, $F = 3$, so departure of F from that value indicate non–gaussianity. Both in SW and in the RFX $F = 3$ at large scales but it increase as the scale decrease, up to $F \simeq 20$ in the SW case (slow wind), and to $F \simeq 50$ in the RFX. The flatness can thus be used to chek the gaussianity of the field fluctuations. In fact, the method introduced by Onorato et al. [4] to separate the field gaussian background from the turbulent structures uses the flatness as an index. In few words, the idea is to compute the local intermittency measure (l.i.m.) introduced by Farge [3] and defined as:

$$L(t,\tau) = \frac{W(t,\tau)^2}{\langle W(t,\tau)^2 \rangle}$$

and to set a dynamical threshold, that reduces until $F = 3$. The rejected wavelet coefficients (that is those higher than the threshold set to have $F = 3$) represents the structures of the field, while the others represents the gaussian (by construction) background. The extracted structures can now be analysed. To eliminate the redundancy effect of the wavelet coefficients on the statistics, we assign a structure to each local maximum of the l.i.m. We can now compute the number of structures for each different scale, and this is an useful quantity to characterize the intermittency in a quantitative way. In figure we plot the number of structures as a function of the time scale for the solar wind and for the RFX. As can be seen, in the SW this number is higher at small scales, so we can argue that intermittency is stronger in the solar wind than in the RFX plasma, according to the previous analysis performed with different methods on the same datasets [5, 6]. Further, we observe that in the RFX the number of structures clearly increases moving thoward the wall, that is intermittency is stronger near the wall. This result is in agreement with the previous analysis [6].

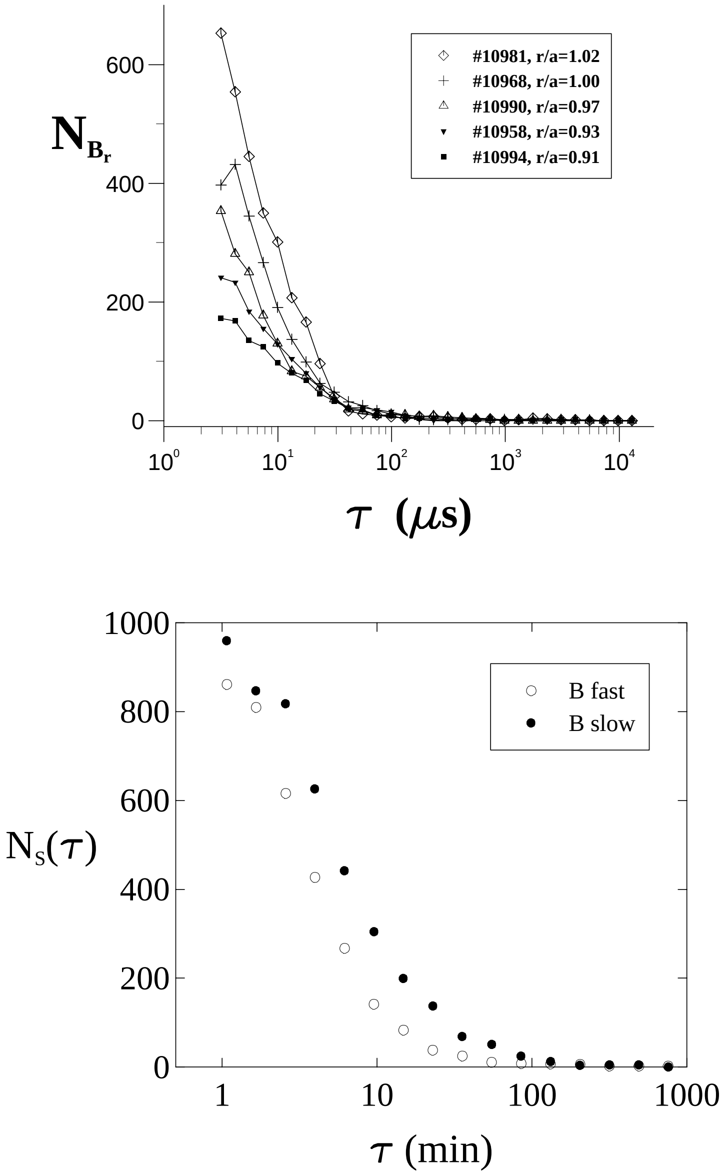

Figure 2. *The number of structures as a function of the scale in the RFX case (upper panel) and in the SW.*

Finally, we show in figure the distribution function of the waiting times between one structure and the following one in the RFX case. The PDF has a power–law behaviour: $P(\tau)\ \tau^{-\gamma}$, instead of the Poisson–like exponential decay expected for a stochastic signal. The values of the scaling exponent $\gamma \simeq 1.5$ seem not to depend on the distance from the wall, that is, on the intermittency strenght. Similar results are obtained in the SW, but with a scaling exponent $\gamma \simeq 2.0$.

In conclusion, we showed that the intermittency is present both in solar wind plasma and in the RFX plasma. We compared the intermittency strenght in different situation using the quantitative tools provided by a wavelet analysis. In particular, we used the l.i.m. to separate the fields in gaussian background and structures.

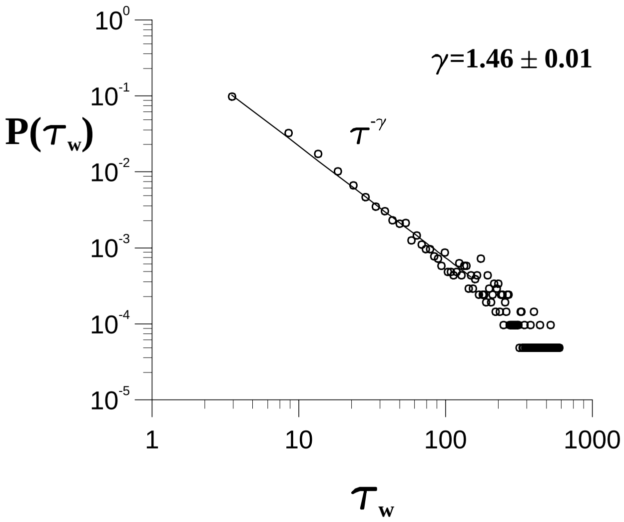

Figure 3. *The PDF of the waiting times between two events in the RFX radial magnetic field. The straight line represents the fit with a power-law.*

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