Mem. S.A.It. Vol. 74, 631
© SAIt 2003

Memorie della

Cancellations analysis of photospheric magnetic structures and flares

L. Sorriso-Valvo[1], V. Abramenko[2], V. Carbone[1], A. Noullez[3], H. Politano[3], A. Pouquet[4] P. Veltri[1] and V. Yurchyshyn[2],

[1] Dipartimento di Fisica, Universitá della Calabria and INFM, Sezione di Cosenza, Ponte P. Bucci, cubo 31 C, I-87030, Rende (CS), Italy e-mail: `sorriso@fis.unical.it`
[2] BBSO, Big Bear City, CA
[3] Observatoire de la Côte d'Azur, Nice, France
[4] ASP/NCAR, Boulder, CO

Abstract. The topological properties of the typical current structures in a turbulent magnetohydrodynamic flow can be measured using the cancellations analysis. In two-dimensional numerical simulations, this reveals current filaments being the most typical current structures. The observations of the topology of photospheric current structures within active regions shows that modifications occur correspondingly with strong flares.

Key words. Flares – Turbulence – Magnetic field

1. Introduction

Solar flares are sudden, transient energy release above active regions of the Sun (Priest (1982)). The magnetic energy is released, and thus observed, in various form as thermal, soft and hard X-ray, accelerated particles etc. It seems natural to look for hints of flaring activity in the magnetic field in the photosphere, but the direct observation of the magnetic field itself gives no unambiguous results (*e.g.* Hagyard et al (1999) and references therein). Recently, unambiguous observations of changing have been reported by Yurchyshyn et al (2000). The authors observed some typical changes of the scaling behavior of the current helicity calculated inside an active region of the photosphere, connected to the eruption of big flares above that active region. In the present paper we conjecture that the changes in the scaling behavior of the observed quantity is related to the occurrence of changes in the topology of the magnetic field at the footpoint of the loop.

2. Signed measure, cancellations and structures

Topological properties of scalar fields which oscillate in sign can be studied through the scaling of signed measures. First of all,

---

Send offprint requests to: L. Sorriso-Valvo
Correspondence to: Ponte P. Bucci, cubo 31 C, I-87030, Rende (CS), Italy

given a meanless, scalar field $f(\boldsymbol{x})$, let us introduce the signed measure

$$\mu_i(r) = \int_{Q_i(r)} f(\boldsymbol{x}) d\boldsymbol{x} \tag{1}$$

through a coarse-graining of non overlapping boxes $Q_i(r)$ of size r, covering the whole field defined on a region of size L. It has been observed (Ott et al, (1992)) that, for fields presenting self-similarity, this quantity displays well defined scaling laws. That is, in a range of scales r, the partition function $\chi(r)$, defined as

$$\chi(r) = \sum_{Q_i(r)} |\mu_i(r)| \sim r^{-\kappa} \tag{2}$$

where the sum is extended over all boxes occurring at a given scale r, follows a power-law behavior

$$\chi(r) \sim r^{-\kappa} . \tag{3}$$

The scaling exponent κ has been called cancellation exponent (Ott et al, (1992)) because it represents a quantitative measure of the scaling behavior of imbalance between negative and positive contributions in the measure. For example, a positive definite measure or a smooth field have $\kappa = 0$, while $\kappa = d/2$ for a completely stochastic field in a d-dimensional space. As the cancellations between negative and positive part of the measure decreases toward smaller scales, we get $\kappa > 0$, and this is the interesting situation. It is clear that the presence of structures, seen as smooth parts of the field, has an important effect on the cancellation exponent. For example, values of $\kappa < d/2$, where d is the dimension of the space (in the present paper $d = 2$), indicate the presence of sign-persistent (*i. e.* smooth) structures.

Within turbulent flows, the value of the cancellation exponent can be related to the characteristic fractal dimension D of turbulent structures on all scales using a simple geometrical argument (Sorriso-Valvo et al (2002)). Let λ be the typical correlation length of that structures, of the order of the Taylor microscale (see for example Frisch (1995)), so that the field is smooth (correlated) in D dimensions with a cutoff scale λ, and uncorrelated in the remaining $d - D$ dimensions. If the field is homogeneous, the partition function (2) can be computed as $(L/r)^d$ times the integral over a generic box $Q(r)$ of size r. The scaling of the latter can be estimated integrating over regular domains of size λ^d and considering separately the number of contributions coming from the correlated dimensions of the field and those from the uncorrelated ones. The integration of the field over the smooth dimensions will bring a contribution proportional to their area $(r/\lambda)^D$, while the uncorrelated dimensions will contribute as the integral of an uncorrelated field, that is proportional to the square root of their area $(r/\lambda)^{(d-D)/2}$. Thus, when homogeneity is assumed, collecting all the contributions in (2) leads to scaling $\chi(r) \sim r^{-(d-D)/2}$ for the partition function, so that one can obtain the simple relation

$$\kappa = (d - D)/2 . \tag{4}$$

3. Solar data

To get a quantitative measure of the change of the scaling of current helicity inside active regions, we used observations of the vector magnetic field obtained with the Solar Magnetic Field Telescope of the Beijing Astronomical Observatory (China). Measurements were recorded in the FeI 5324.19 Å spectral line. The field of view is about 218" × 314", corresponding to 512 × 512 pixels on CCD. The magnetic field vector at the photosphere has been obtained through the measurements of the four Stokes parameters, and the current density $J_z(x, y)$ has been calculated as a line integral of the transverse field vector over a closed contour of dimension 1.72" × 1.86" (cf. Yurchyshyn et al (2000) for details). The current helicity $H_c = \mathbf{B} \cdot \mathbf{J}$ (where $\mathbf{B}$ represents the magnetic field and $\mathbf{J} = \nabla \times \mathbf{B}$ the current density) is a measure of small scales activity in magnetic turbulence. It indicates the degree of clockwise

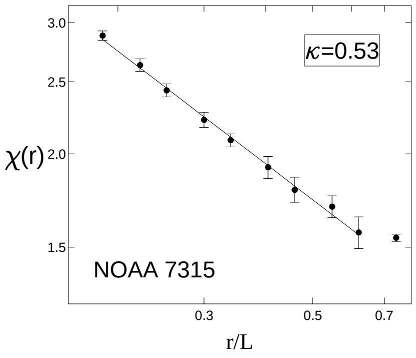

Fig. 1. The scaling of the partition function for a flaring active regions (NOAA 7315), which started to flare on October 22, 1992. The power-law fit is indicated as a dotted line.

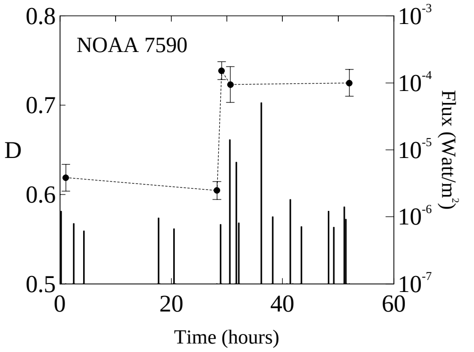

Fig. 2. We present one flaring event observed in 1993 (see text for description) in the bottom part of the plot (line bars, in arbitrary units). The corresponding time variation of the fractal dimension D is reported (symbols).

or anti-clockwise knotness of the current density. Let us consider a magnetogram of size L taken on the solar photosphere of an active region, and let $\mathbf{B}_\perp(x,y)$ the observed magnetic field perpendicular to the line of sight ((x,y) are the coordinate on the surface of the sun). Through this field we can measure the surrogate of current helicity, that is $h_c(x,y) = B_z(x,y)J_z(x,y)$ being $J_z(x,y) = [\nabla \times \mathbf{B}_\perp] \cdot \hat{\boldsymbol{e}}_{\boldsymbol{z}}$. A signed measure can be defined from this quantity, $\mu_i(r) = \int_{Q_i(r)} h_c(x,y)dxdy$. In Figure 1 we show, as example, the scaling behavior of $\chi(r)$ vs. r for a flaring active region (NOAA 7315) which started to flare on October 22, 1992. At larger scales we find $\chi(r) \sim const.$, and this is due to the complete balance between positive and negative contributions. The same behavior does not appear at smaller scales, showing that the resolution of the images is not high enough to resolve the smallest structures. In the intermediate region of scales, the cancellation exponent is found to be $\kappa = 0.53 \pm 0.09$ (Yurchyshyn et al (2000)). We now study the fractal dimension of current structures D as a function of time. To this aim, we take different consecutive magnetograms of the same active region, and for each magnetogram, we compute the value of κ and then of D through relation (4). In Figure 2, we report the time evolution of D superimposed to the flares occurred in two active regions, namely NOAAs 7315, and 7590 (which flared on October 1, 1993). The fractal dimension D, starting from a given value ($D < 1$), becomes abruptly larger in correspondence with a sequence of big flares occurring at the top of the active region into the corona. The same behavior has been found for all calculations in all active regions we examined. The increase of the dimension of the structures may be the signature that dissipation has occured. In fact, annihilation is responsible for the smoothing of the small scales structures.

4. Conclusions

In this paper we point out that the changes in the scaling behavior of cancellations, measured through the cancellation exponent κ, are due to the topology changes of the structures present in the field, and are thus related to the importance of dissipative effects. The non-linear turbulent cascade, underlying the formation os such structures on all scales, can be considered as one important input mechanism for flares. The results obtained from the analysis of the numerical simulations can be considered as a test for our model for the fractal dimension of structures, thus supporting our interpretation of the observational results for the photospheric magnetic field in the active regions. To conclude, it is evident that the behavior we found can be used as a signature of the occurrence of big flares. High energy solar flares become of great interest because they can produce severe damages on Earth. Power blackouts, break up of communications and mainly damage of satellites or space flights, can be ascribed to energy released during big solar flares. It is then evident that the possibility of forecasting, even if partially, high energy flares has a wide practical interest to prevent the effects of flares on Earth and its environment. We build up a model which allows us to recognize without ambiguity changing behavior of the photospheric magnetic field of active regions. These changes, pointed out through the variation of a scaling index for current helicity, can be seen mainly before the eruption of big flares. The change of scaling index is due to the turbulent and intermittent energy cascade towards smaller scales, a mechanism which could be identified as the input of flaring activity, where energy is dissipated. The method could allows us to forecast, in real time, the appearence of the strongest flaring activity above active regions.

References

Frisch U., *Turbulence: the legacy of A. N. Kolmogorov*, Cambridge U. P., 1995.

Hagyard M.J., Stark B.A., & Venkatakrishnan P., Sol. Phys. 184, 133, 1999.

Ott E., Du Y., Sreenivasan K.R., Juneja A., & Suri A.K., PRL 69, 2654, 1992.

Priest E., *Solar Magnetohydrodynamic*, D. Reidel Publishing Company, Dordrecht, 1982.

Sorriso-Valvo L., Carbone V., Noullez A., Politano H., Pouquet A., & Veltri P., Phys. Plasmas 9, 89, 2002.

Yurchyshyn V.B., Abramenko V.I., & Carbone V., ApJ 538, 968, 2000.