SIGN–SINGULARITY OF THE CURRENT HELICITY IN SOLAR ACTIVE REGIONS

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Abstract. On the basis of vector magnetograms of 20 active regions we analyzed the scaling behavior of the current helicity H_c in the photosphere. We show that H_c possesses well pronunced sign–singularity in the range of scales from more than 10^4 Km up to the resolution limit of observations.

We analyze scaling properties of the current helicity in active regions (ARs) on the Sun. We used measurements of the magnetic field vector **B** obtained with the Solar Magnetic Field Telescope (SMFT) of the Beijing Astronomical Observatory (China). Measurements were recorded in the FeI 5324.19 Å spectral line. The field of view is about $218'' \times 314''$ (512×512 pixels of the CCD). Since we have information on **B** only at one layer on the photosphere, we can calculate only a part of the photospheric current helicity:

$$H_c = B_z \cdot (\nabla \times \mathbf{B})_z \tag{1}$$

The data processing and the algorithm for H_c calculation are described in detail by Abramenko et al. (1996).

The scaling properties of the current helicity H_c in AR maps can be analyzed by introducing the signed measure

$$\mu_i(r) = \frac{\int_{L_i(r)} H_c(x,y)dx\,dy}{|\int_{L(R)} H_c(x,y)dx\,dy|}, \tag{2}$$

where $L_i(r) \subset L(R)$ represents a hierarchy of disjoint squares, of size r, covering the whole square L of size R which encloses an AR. Then we investigate the behavior of the alternate in sign, scale by scale, of the measure by defining a scaling exponent κ (Ott et al., 1992)

$$\chi(r) = \sum_{L_i(r)} |\mu_i(r)| \sim r^{-\kappa}, \tag{3}$$

For a probability measure, defined positive, we obtain the trivial value $\kappa = 0$. In order to get $\kappa > 0$, the sum must increases as $r \to 0$, and this is verified only if the cancellations between positive and negative contributions in μ_i reduces as $r \to 0$. When this is true the measure is said to be sign–singular and the scaling exponent

κ is called *cancellation exponent*. In general, for a random process embedded in a D–dimension space, $\kappa = D/2$. Nontrivial examples of physical situations displaying this kind of singularity which causes anomalous cancellations can be found in Ott et al. (1992), Vainshtein et al. (1994), Bertozzi and Chhabra (1994), Carbone and Bruno (1996, 1997).

Let the scale r be measured in pixels in terms of the largest scale R. We analyze boxes of different sizes, from $R = 126$ pixels to $R = 48$ pixels. As the signed measure has been obtained through (3), by the visual inspection we choose the linear interval in the plots of $\log \chi(r)$ vs. $\log(r/R)$, and finally the cancellation exponent was calculated as the linear best fit. For some given magnetograms we calculated the cancellation coefficient for several boxes R within a given area. We choose a set of N positions of the box R on the map in such a way that the boundary of the box do not cross the main maxima of the field H_c. Besides, quite areas should be minimally involved in the box. Inside each box the function $\chi(r)$ was calculated, as well as the scaling exponent κ_m, $(m = 1, \ldots, N)$. Finally for each AR the average cancellation exponent $\kappa = \sum_{m=1}^{N} \kappa_m/N$, and their r.m.s. deviation, were calculated as a characteristic of each AR. All results are collected in the Table. The analysis of a large bipolar active region can be made by separate examination of its leading and following parts (L/F in the Table). Compact ARs such as δ-configurations, unipolar spots, small compact bipolar ARs, were analyzed as a whole and they are marked by the letter W in the Table.

In Fig.s 1 we show the results relative to the large bipolar active region NOAA 7316. A nice sign–singularity is present, with a well defined value of κ, in the region between 10^4 Km up to the resolution limit of the measurements, say about 10^3 Km. Looking at the Table we can see that there is a systematic tendency for the cancelation exponent in the leading part of an AR to be smaller than that in the following part. We think that such a difference between κ in the leading and following part is caused by the fact that the magnetic field of the leading spot, as a rule, is more compact than that in the following part. This fact must be reflected in the structure of H_c.

All the δ-configurations studied here shown close values, from $\kappa = 0.38$ up to $\kappa = 0.44$. As a rule the scaling law in δ–structures is well pronounced.

In summary we have shown that well pronounced scaling laws take place for 2D structures of current helicity in ARs, indicating that the signed measure obtained with H_c is sign–singular, say the cancellations follow a nontrivial anomalous scaling. The cancellation exponent $\kappa = 0.3 - 0.7$ we obtain is significantly larger than that obtained for the vertical magnetic field (Lawrence et al., 1993). This indicates rapid oscillations of the transverse magnetic field which generates the current.

The linear region on the measure is well pronounced and can be determined reliably in such a way that there are the reasons to suppose that they extend with the same scaling below the limit of our resolution. Then, even if it is below the resolution of measurements, the scaling law we found for the cancellations allow us to conjecture that a well defined sign of H_c is present at scales less than 10^3 Km. As shown by Seehafer (1994) the condition for the alpha–effect taking place within some volume is the non–zero imbalance of current helicity over the volume. Our analysis show that at any scale the dominance of current helicity of some sign takes place, so, the condition for the alpha–effect is performed.

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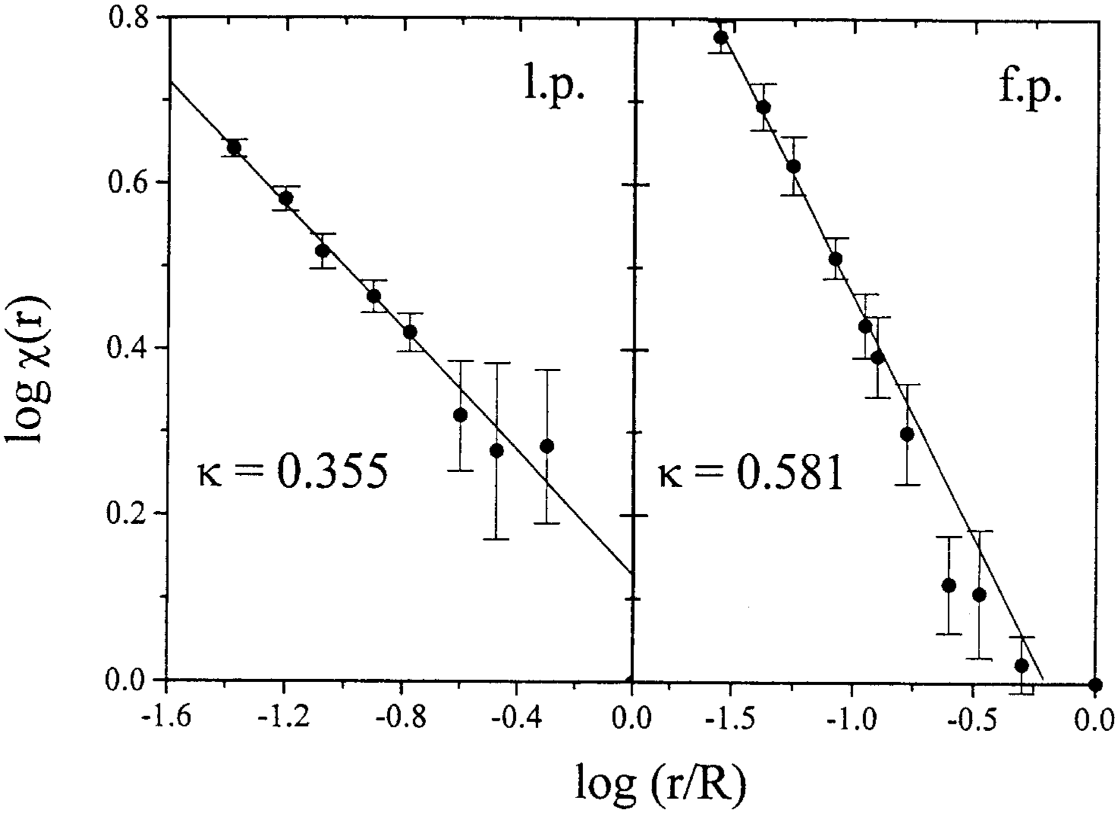

Fig. 1: We show the partition function $\log\chi(r)$ vs. $\log(r/R)$ for the active region NOAA 7316 (*left*) for the leading part (l.p., $R = 48$), (*right*) for the following part (f.p., $R = 72$). Dotted lines indicate the linear best–fit over the last 5 points.

Table 1: Cancellation exponents κ for 20 studied active regions

NOAA	Date	UT	κ	Remark
5747	Oct 19,89	04:28	0.42±0.02	W
	Oct 20,89	01:37	0.38±0.01	W
5948	Feb 26,90	01:24	0.36±0.03	L
			0.62±0.03	F
6001	Apr 06,90	03:41	0.32±0.03	L
			0.53±0.05	F
6272	Sep 21,90	05:30	0.38±0.03	W
6659	Jun 09,91	03:52	0.44±0.01	W
		05:29	0.41±0.01	W
6757	Aug 04,91	01:42	0.43±0.04	L
			0.50±0.02	F
6786	Aug 20,91	02:19	0.43±0.02	L
			0.63±0.06	F
6850	Oct 03,91	01:28	0.44±0.03	L
			0.65±0.03	F
		02:41	0.48±0.04	L
			0.66±0.03	F
		03:21	0.48±0.05	L
			0.69±0.05	F
6853	Oct 03,91	01:41	0.39±0.07	L
			0.64±0.06	F
6855	Oct 03,91	02:01	0.37±0.02	L
			0.54±0.04	F
6891	Oct 30,91	02:42	0.43±0.02	
7216	Jul 04,92	00:29	0.41±0.05	L
			0.60±0.01	F
7294	Sep 29,92	02:08	0.23±0.02	W
7315	Oct 20,92	03:32	0.52±0.03	W
7316	Oct 23,92	03:27	0.36±0.02	L
			0.58±0.03	F
7321	Oct 26,92	03:34	0.43±0.04	W
7496	May 09,93	01:44	0.45±0.04	W
7585	Sep 24,93	06:00	0.35±0.03	W
7590	Oct 03,93	03:59	0.52±0.02	F
7597	Oct 15,93	04:41	0.41±0.04	W
		05:49	0.47±0.02	W