Early Diagnostics of Dangerous Active Regions

Valentyna Abramenko
Big Bear Solar Observatory of NJIT
Email:avi@bbso.njit.edu

Introduction

"**The magnetic stress** released in a flare may either have been **generated in the convection zone** and hence **is already present when the field emerges** from the photosphere, or is built up gradually in the corona due to the effect of photospheric motions at the field line feet."

(Biskamp "Nonlinear Magnetohudrodunamics", Cambridge Univ. Press, 1993.)

Our goal: to reveal the parameters of the emerging magnetic field which are relevant to the future flare productivity of an active region.

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Approach

1. Calculate the magnetic power spectrum, $E(k) \sim k^{-\alpha}$, from line-of-sight magnetograms B_z of different active regions and to determine the power index α.

1. Calculate the soft X-ray flare index, *A*, which characterizes the flare productivity of an active region.

3. Compare the power index α with the soft X-ray flare index *A*.

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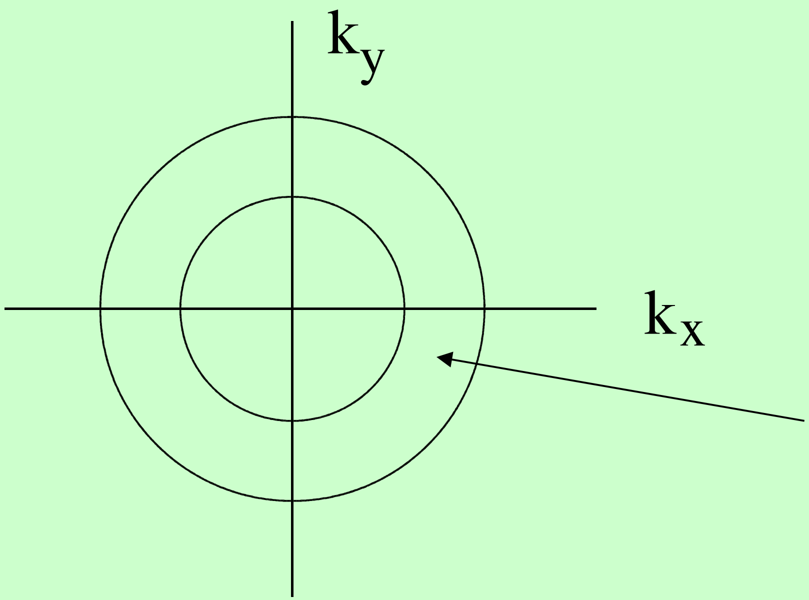
Magnetic power spectrum from B_z

A power spectrum of 2D real function $B_z(\vec{r})$ is defined as

$$E(k) = \int_{|\vec{k}|=k} |b(\vec{k})|^2 \cdot dS(\vec{k}),$$

where $b(\vec{k})$ is the Fourier transform of $B_z(\vec{r})$ and $\vec{k}$ is a wave vector. $dS(\vec{k})$ is an element of the length of circle $|\vec{k}| = k$.



Integration of $|b(\vec{k})|^2$ inside the annulus in the wave-number space gives us $E(k)$

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Soft X-ray Flare Index

Antalova 1996 — Pevtsov 2004 *private communication*

Landi et al. 1998 — Longcope 2005 *private communication*

$$A = (100S^{(X)} + 10S^{(M)} + 1.0S^{(C)} + 0.1S^{(B)})/\tau,$$

where $S^{(j)} = \sum_{i=1}^{N_j} I_i^{(j)}$ is the sum of GOES peak intensities of a certain class,

$N_j = N_X, N_M, N_C, N_B$ are the numbers of flares of X, M, C, B classes

that occurred in a given active region during the time interval τ.

τ is the across-the-disk passage time (measured in days).

For example, during $\tau \approx 13$ days an active region launched flares:

X5.2 , M1.2 , C6.0

$A=(520 + 12 + 6.0) / 13 = 41.4$ (in units 10^{-6} W m^{-2})

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Main Result: Soft X-ray Flare Index versus Magnetic Power Index

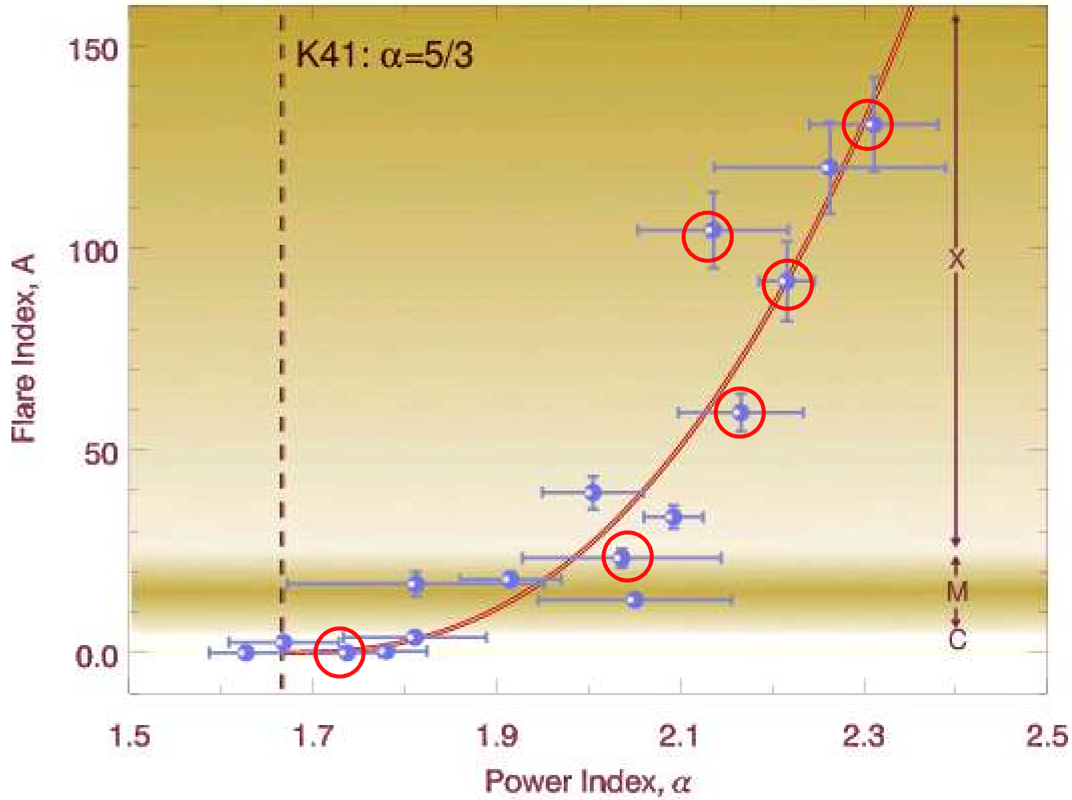

Fig. 8.— Power index α versus flare index A plotted for 16 active regions listed in Table 1. The dashed straight line indicates the power index $\alpha = 5/3$ for the stationary classical Kolmogorov turbulence K41. The curve shows the best fit $A(\alpha) = 409.5(\alpha - 5/3)^{2.49}$ to the data.

Red circles mark the emerging active regions.

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Conclusions

1. Non-flaring active regions possess Kolmogorov-type spectra, whereas “dangerous” active regions that launched X-class flares display much steeper, non-Kolmogorov’s spectra.

2. The non-Kolmogorov spectrum was observed since the very beginning of the emergence of flaring active regions.

8. This finding shows the way to distinguish at the very early stage dangerous active regions that have a potential to produce powerful flares.

The study was published in : **ApJ 629:1141-1149, 2005**

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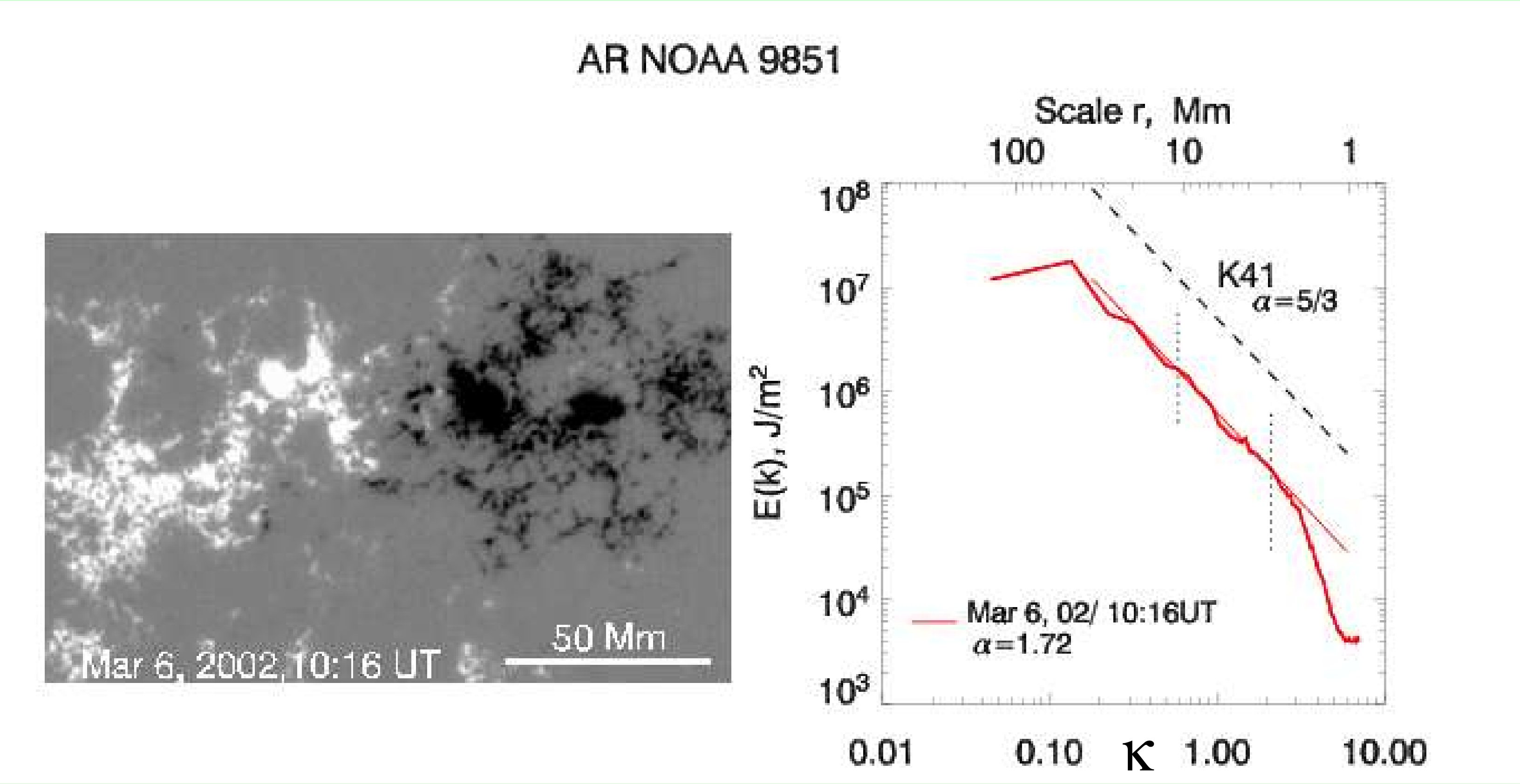
Emerging Non-Flaring Active Region



For non-flaring active regions the power index α in $E(\kappa) \sim \kappa^{\alpha}$ is very close to the Kolmogorov’s 5/3 index.

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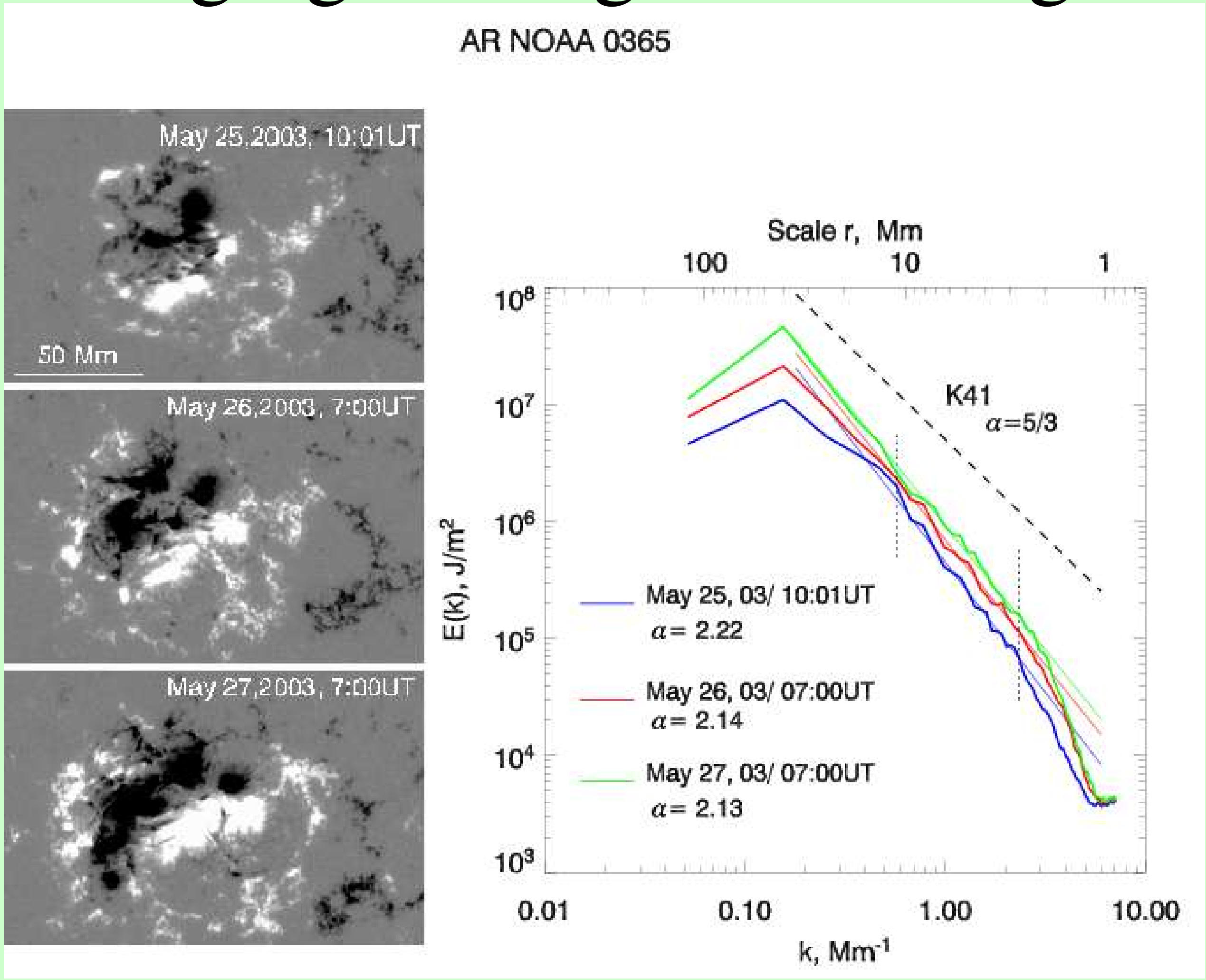
Emerging Flaring Active Region



Since the very beginning of emergence until the end of observation period the power spectrum has been steeper than the Kolmogorov's spectrum K41.

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Table 1: Active Regions

Table 1: List of studied active regions and calculated parameters

NOAA AR and magnetic type	Period of observations	N[a]	Strongest Flare, X-ray class	Flare Index, A	Power index $\alpha, (3-10)$Mm	Power index $\alpha, (2-20)$Mm
0375 (emerging $\beta\gamma\delta$)	Jun 6-8, 2003	13	X1.7	130.6	2.311 ± 0.070	2.329 ± 0.104
9077 (stable $\beta\gamma\delta$)	Jul 13-14, 2000	559	X5.7	119.9	2.263 ± 0.126	2.281 ± 0.150
0365 (emerging $\beta\gamma\delta$)	May 25-27, 2003	520	X3.6	104.4	2.136 ± 0.082	2.133 ± 0.090
0488 (emerging $\beta\gamma\delta$)	Oct 29, 2003	2	X3.9	91.8	2.216 ± 0.030	2.211 ± 0.027
0030 (emerging $\beta\gamma\delta$)	Jul 15-16, 2002	8	X3.0	59.3	2.166 ± 0.068	2.187 ± 0.045
0501 (stable $\beta\gamma\delta$)	Nov 18-19, 2003	12	M9.6	39.5	2.005 ± 0.055	2.058 ± 0.114
9661 (stable $\beta\gamma\delta$)	Oct 16-17, 2001	7	X1.6	33.5	2.093 ± 0.032	2.112 ± 0.026
9773 (emerging $\beta\gamma\delta$)	Jan 8-9, 2002	6	M9.5	23.4	2.036 ± 0.108	2.049 ± 0.061
0134 (stable $\beta\gamma\delta$)	Sep 30-Oct 1, 2002	5	M2.6	18.2	1.915 ± 0.055	1.974 ± 0.039
8375 (stable $\beta\gamma$)	Nov 4-5, 1998	6	M2.7	17.0	1.812 ± 0.140	1.822 ± 0.097
9866 (stable $\beta\delta$)	Mar 14-15, 2002	9	M5.7	13.1	2.051 ± 0.105	2.059 ± 0.028
0149 (stable $\beta\gamma$)	Oct 14-16, 2002	18	M1.0	3.8	1.811 ± 0.078	1.843 ± 0.043
0061 (stable $\beta\gamma$)	Aug 9, 2002	429	C3.3	2.6	1.668 ± 0.060	1.768 ± 0.022
0306 (stable $\beta\gamma$)	Mar 13-14, 2003	3	C2.6	0.4	1.780 ± 0.044	1.816 ± 0.024
9851 (emerging β)	Mar 6, 2002	4	-	0.0	1.737 ± 0.035	1.733 ± 0.020
0515 (decay β)	Dec 3, 2003	2	-	0.0	1.627 ± 0.040	1.635 ± 0.023

[a]– number of analyzed magnetograms.

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Table 2: Emerging Active Regions

Table 2: List of emerging active regions and calculated parameters

NOAA AR	Flare Index, A	Time of the first magnetogram	α from the first magnetogram [a]	$<\alpha>$ [a,b]
0375	130.6	Jun 6, 2003, 20:26 UT	2.22	2.31
0365	104.4	May 25, 2003, 10:01 UT	2.23	2.14
0488	91.8	Oct 29, 2003, 15:47 UT	2.22	2.22
0030	59.3	Jul 15, 2002, 10:54 UT	2.20	2.17
9773	23.4	Jan 8, 2002, 20:23 UT	1.94	2.04
9851	0.0	Mar 6, 2002, 10:13 UT	1.74	1.74

[a]– the power index α was calculated over the $(3-10)$ Mm range of scales.
[b]– $<\alpha>$ is the power index averaged over all analyzed magnetograms as it is presented in the 6-th column of Table 1.

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Discussion

Kolmogorov-type spectra of non-flaring active regions might Suggest the presence in an active region of a nearly stationary Turbulent regime when the dynamical equilibrium between the input of energy at large scales and output at small scales provides premises for smooth evolution without catastrophes.

On the other hand, the non-Kolmogorov’s spectra of flaring active regions imply the inhomogeneous non-stationary turbulence when the dissipation of energy might occur in a burst-like manner.

The result might suggest that **the magnetic stress generated in the convection zone** may to a high degree determine the future flare productivity.