Multi-Wavelength Investigations of Solar Activity
Proceedings IAU Symposium No. 223, 2004
A.V. Stepanov, E.E. Benevolenskaya & A.G. Kosovichev, eds.
© 2004 International Astronomical Union
DOI: 10.1017/S1743921304006568

Detection of a Taylor-like Plasma Relaxation Process in the Sun and its Implication for Coronal Heating

Dibyendu Nandy[1], **Michael Hahn**[2], **Richard C. Canfield**[1] **and Dana W. Longcope**[1]

[1]Department of Physics, Montana State University, Bozeman, MT 59717, USA
email: nandi@mithra.physics.montana.edu

[2]Department of Physics, Carnegie Mellon University, Pittsburgh, PA 15213, USA

Abstract. The relaxation dynamics of a magnetized plasma system is a subject of fundamental importance in MHD – with applications ranging from laboratory plasma devices like the Toroidal Field Pinch and Spheromaks to astrophysical plasmas, stellar flaring activity and coronal heating. Taylor in 1974 proposed that the magnetic field in a plasma (of small but finite resistivity) relaxes to a minimum energy state, subject to the constraint that its total magnetic helicity is conserved (Woltjer 1958), such that the final magnetic field configuration is a constant α (linear) force-free field – where α is a quantity describing the twist in magnetic field lines. However, a clear signature of this mechanism in astrophysical plasmas remained undetected. Here we report observational detection of a relaxation process, similar to what Taylor (1974, 1986) envisaged, in the magnetic fields of flare-productive solar active regions. The implications of this result for magnetic reconnection and the coronal heating problem are discussed.

1. Summary of Main Results

In astrophysical and laboratory plasma systems where the plasma-β parameter (the ratio of the gas to magnetic pressure) is low (< 1), the magnetic stresses in the field lines permeating the plasma become unbalanced and the magnetic field evolves in a self-organized manner to remove these stresses. The lower solar corona is a low β plasma and its magnetic field is believed to be nearly force-free. Coronal magnetic fields or loops are associated with solar active regions (ARs) with their foot points anchored slightly beneath the photosphere. The kinetic energy of the foot point motions (due to convective turbulent flows) can be transmitted into overlying tangled magnetic loops, the subsequent reconnection (and flaring activity) of which would be able to heat and maintain the solar corona by a Taylor-like relaxation process towards a linear force-free field configuration (Parker 1983; Heyvaerts and Priest 1984).

We did a statistical study of the evolution of twists (quantified by the parameter $\alpha_Z(x,y)$ as measured from Haleakala Stokes Polarimeter vector magnetograms) in a sample of flare-productive solar ARs (which had flare X-ray flux measurements from the GOES satellite) to seek possible signatures of relaxation towards a Taylor-like state (Nandy et al. 2003). As shown in Figure 1 (left), the variance in the $\alpha_Z(x,y)$ distribution shows a statistically significant decrease over the flaring period for highly flare-productive solar ARs (at a confidence level of 98.95 %). Note that the variance indicates how non-uniform is the value of $\alpha_Z(x,y)$ over the AR flux system and a decrease in this quantity implies an evolution towards a more uniform state. Therefore we find that AR flux systems (which were highly flare-productive, i.e., showing a high value of the integrated flare energy flux E_f) tend to evolve towards a linear force-free state. However, they never

https://doi.org/10.1017/S1743921304006568 Published online by Cambridge University Press

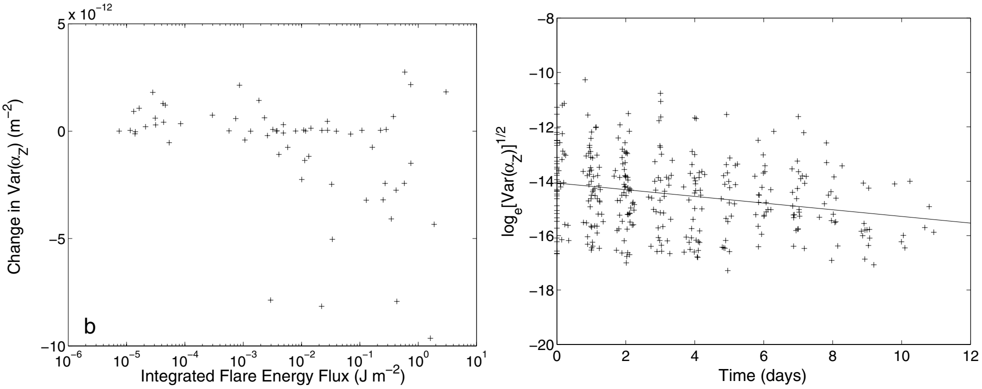

Figure 1. Left: Change in Variance of $\alpha_Z(x, y)$ distribution for each AR (over the flaring period) versus its integrated flare energy flux E_f. Right: Evolution of $\log_e[\mathrm{Var}(\alpha_Z)]^{1/2}$ values versus normalized time of observations in days. The solid line shows the best linear fit to the data.

achieve a completely linear state. From Figure 1 (right), where we plot the time evolution of $\log_e[\mathrm{Var}(\alpha_Z)]^{1/2}$ values, one can calculate the timescale for this relaxation assuming that the above parameter diffusively decays ($\sim \mathrm{e}^{-t/\tau}$) with a characteristic timescale τ. The timescale of this relaxation process turns out to be 8.1 days, i.e., on the order of a week.

Assuming that the diffusion of the twist parameter α is due to small-scale reconnection between neighboring flux tubes, our derived relaxation time implies a slower reconnection rate then expected from turbulent fast reconnection ($\sim 10^5$ s, roughly one day) as in Petschek's model (Petschek 1964). For this kind of reconnective transport to yield the slower relaxation observed would require that each flux bundle undergoes reconnection occasionally rather than continuously. Also, theoretical studies show that the heating of the solar corona from the energy available from photospheric foot point motions is maximized when the timescale of relaxation (or reconnection) of the coronal loops is higher than the timescale of photospheric foot point motions (thus in effect allowing enough stresses to build up before reconnection can release it). The latter is of the order of 1 day for AR flux systems and our estimated relaxation time ($\sim$ week) is higher than that. Thus our result may be taken as observational evidence that the plasma relaxation mechanism, in response to photospheric foot point motions, is a viable mechanism for coronal heating.

For a detailed description of our analysis and results interested readers are referred to Nandy et al. (2003). This research has been supported by NASA through Science Research & Technology grant NAG5-11873.

References

Heyvaerts, J., & Priest, E. R. 1984, A&A, 137, 63

Nandy, D., Hahn, M., Canfield, R. C., & Longcope, D. W. 2003, ApJ Letters, 597, L73

Petschek, H. E. 1964, in The Physics of Solar Flares, ed. H. E. Hess (Proceedings of the AAS-NASA Symposium; Washigton, DC), 425

Taylor, J. B. 1974, PRL, 33, 1139

Taylor, J. B. 1986, Rev. Mod. Phys., 58, 741

Woltjer, L. 1958, Proc. Nat. Acad. Sci. (USA), 44, 489

https://doi.org/10.1017/S1743921304006568 Published online by Cambridge University Press