MAGNETIC SHEAR AND FLARES

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ABSTRACT. Magnetic tension posseses low values at regions of large magnetic "shear" on the polarity inversion line. The low tension allows for a non-force-free field that depends on the density of the medium. Instabilities which can modify the density may then possibly evolve into solar flares. Heuristic arguments are given to favour instability driven flare scenarios.

1. Introduction

With the advent of vector magnetographs, the non- potential nature of pre-flare magnetic configurations could be clearly discerned from the angular deviation of the observed transverse component of the magnetic field from the transverse potential field calculated from the distribution of the line- of-sight component of the magnetic field. This angular deviation, called magnetic "shear" was seen to be large at locations of four major flares (Hagyard, *et al.*, 1984; Hagyard, Venkatakrishnan, and Smith 1989). A theoretical basis for such a correlation was suggested in terms of the loss in magnetic tension caused by a shear in the field (Venkatakrishnan, 1990). In this paper, we advance arguments in support of instability driven scenarios for flares.

2. Loss of Magnetic Tension in Sheared Fields

The magnetic pressure gradient balances the magnetic tension in a force free field. The vertical component of the tension force is given by $\mathbf{B}_T . \nabla_T B_z$ where $\mathbf{B}_T$ is the transverse component of the magnetic field and ∇_T is the lateral gradient operator, $(\mathbf{x}\partial/\partial x, \mathbf{y}\partial/\partial y)$. The maximum tension is available in a potential configuration, where the gradient of B_z is along $\mathbf{B}_T$. Near a polarity inversion line, this is manifest by $\mathbf{B}_T$ pointing across the line. For a sheared field, $\mathbf{B}_T$ is almost aligned with the inversion line, thereby providing a smaller tension force as compared to a potential field. A force free field must respond to this loss of tension by a decrease in the vertical gradient of magnetic pressure. This conclusion is also borne out in detailed computations (Wu *et al.*, 1990). If the gradient in magnetic shear is small, then this extention of B_T^2 must persist to greater heights. The interaction of this vertically extended transverse field with the over-lying global field through reconnection would then be able to "open" out the

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configuration and release the excess energy stored in the closed field in the form of a solar flare. There is another possibility where the gradient of B_T^2 does not have to match the low magnetic tension of the sheared field, but is balanced by the weight of the material ρg. This could happen, for instance, in an active region filament .where the density is larger than the ambient value. Such a field with magnetic pressure gradient balancing ρg will depend on the plasma density. Any decrease in ρ caused, e.g. by extra heating could possibly become a runaway process via a thermal instability. The "lifting" of the field lines in response to the decrease of ρg would drain material away from the region leading to a further decrease in ρg. The rearrangement of the field lines caused by this instability could lead to centri- fugal acceleration of plasma along the field lines (Venkatakrishnan, 1984a,b) resulting in shocks and eventually flares. Alternatively, the electric field induced by the rapidly changing magnetic field could be trapped for particle acceleration (Colgate, 1978). The details of this scenario are given in an earlier paper (Venkatakrishnan,1990).

3. Instability vs Non-Equilibrium Driven Scenarios

Onset of non-equilibrium of a slowly evolving field as it cro- sses a critical parameter was suggested as a possible way of converting the magnetic energy stored in a non-potential field on a very short time scale (Low,B.,C.,1982). In all cases where a critical parameter was identified, it was seen that a change in the parameter involved specifying unphysical boundary conditions. In cases were evolution of the field was modelled on the basis of physical boundary conditions, e.g. by moving the footpoints of the field lines, no loss of equilibrium was encountered (Zwingmann, 1989). Observational identification of such a critical parameter has also met with only limited success. A promising parameter seemed to be magnetic shear. However, there are examples where the shear was large on the neutral line for several days without any flare in the active region (Hagyard, Venkatakrishnan, and Smith, 1989). On the other hand, there is growing evidence for pre-flare activation of filaments several minutes before the impulsive phase (Kahler *et al.*, 1988). Soft X-ray enhancement is also seen several minutes before the flare. The buoyancy time scale, given by $(\Lambda/g)^{1/2}$, is $\approx$ 5 minutes for a scale height Λ of 10^9 cm. This could be construed as a support for the instability driven scenario for the flare outlined in the previous section. The observed pre-flare heating could then be interpreted as the progress of the thermal instability. The Alfven travel time, which is the relevant time scale for non-equilibrium, is tens of seconds for a similar length scale and a field strength of a few hundred Gauss. If this short time scale is equated with the timescale for the impulsive phase of the flare, then the pre-flare activation requires an additional explanation in the non-equilibrium scenario. On the other hand, an instability driven scenario would require a pre-flare stage on the buoyancy timescale, while the onset of the flare proper can be interpreted as the the onset of reconnection caused by large magnetic field gradients or electric fields created from the rapidly changing magnetic field.

4. Discussion and Conclusions

Choosing between instability driven and non-equilibrium driven flare scenarios is not a pedagogical exercise. Observers, in particular, are interested in clues that would help in predic- ting the location and time of flare onset. A non-equilibrium scenario implies the search for a critical parameter of the equilibria, while the thermal instability scenario implies the search for triggers. Although the Skylab data showed some evidence for triggers, the SMM results did not prove to be eq- ally convincing. The modelling of the 3-D magnetic configuration based on boundary conditions specified at the photosphere will also help in discriminating between potentially flaring and non-flaring regions with equal extent of magnetic shear along the polarity inversion line. A promising criterion is the vertical gradient of shear reflected, perhaps, in the lateral gradient of the shear across the neutral line. Searching for similar criteria in observed vector magnetograms will be certainly useful. The expectation is that configurations with a smaller vertical gradient of magnetic shear exert more pressure on the overlying field and thus should be more prone to erupt in a flare. In conclusion, the signature of large shear at flare sites allows us to consider instability driven scenarios for flares. The failure to identify a critical parameter for loss of equilibrium either from specifying physical boundary conditions or from observations should urge us to look beyond the non-equilibrium driven flare scenarios.

References

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DISCUSSION

VARMA: What instability are you envisaging?

VENKATAKRISHNAN: I am envisaging a thermal instability for this process, but have not done any stability analysis to identify it precisely.

VERMA: (i) Is there any relation between magnetic shearing in the active region and the type of solar flares?
(ii) Can we know on the basis of magnetic shearing in the active region whether the flares will be impulsive or gradual?

VENKATAKRISHNAN: (i) The observations of vector magnetic fields in active regions so far have concentrated on two-ribbon flares. We do not know yet whether compact flares are associated with locations of large magnetic shear or whether these can be produced even in less sheared regions.

(ii) Since the association of flares with magnetic shear has been established for very few cases, it is difficult to give any prediction on the absence or presence of the impulsive phase based purely on the shear.