IMPLICATIONS OF TENSION FREE EQUILIBRIA FOR PRE-FLARE ENERGY BUILDUP

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ABSTRACT: The downward tension force is known to be extremely small at the locations of highly sheared magnetic fields. The free energy in such tension free fields is shown to be dependent on the plasma density. The excess of this free energy over that available in a force free configuration is estimated and shown to be sufficient to drive instabilities which could possibly initiate a solar flare.

1. Introduction

Magnetic shear, (as measured by the angular deviation of the observed transverse field from a potential transverse field), was seen to be large at sites of major flares (Hagyard, *et.al.*, 1984; Hagyard and Rabin, 1986; Hagyard, Venkatakrishnan, and Smith, 1989). Large magnetic shear was shown to be equivalent to low magnetic tension, which implied that the magnetic fields were dependent on the plasma density, thereby allowing for plasma instabilities to destabilise the magnetic configurations (Venkatakrishnan, 1990). In this paper, we will estimate the excess energy stored in a tension free field over and above that stored in a force free field.

2. Estimation of Excess Energy in Tension Free Fields

A lower limit to the free energy in a sheared magnetic field can be obtained by assuming that the shear is produced by only a rotation of the transverse magnetic field from its potential configuration through the shear angle without any increase in field strength (Moore,R.,L.:1988,personal communication). This gives the free energy as

$$E \simeq 4.(B_T^2/8\pi).\sin^2\vartheta/2 \quad , \tag{1}$$

where B_T is the transverse field and ϑ is the shear angle.

The shear angle for a force free field can be obtained by equating the magnetic pressure and tension forces. This gives

$$\partial B_T^2/\partial z \approx 2.\ B_T.\nabla B_z \ , \quad \text{or} \quad B_T^2/\Lambda_B \approx 2.B_T.B_z.\cos\vartheta\ /\Delta \quad , \tag{2}$$

where Λ_B is the magnetic scale height and Δ signifies the lateral scale of variation of the vertical component of the magnetic field. When the plasma density is sufficiently high, then a further reduction in the tension force is possible which would be replaced by the downward force of gravity. This reduction can thus be expressed in terms of the weight

E. R. Priest and V. Krishan (eds.), Basic Plasma Processes on the Sun, 323–324.

https://doi.org/10.1017/S0074180900088185 Published online by Cambridge University Press

of the material. By equating the variation of the tension force (R.H.S. of equation 2) caused by a change $\delta\vartheta$ in the shear angle with the weight of the material ρg, we have

$$\sin\vartheta . \delta\vartheta \approx 4\pi\rho g\Delta/B_T B_z \qquad (3)$$

The increase in the free energy given by (1) caused by the change in angle $\delta\vartheta$ can be similarly obtained from

$$\delta E \approx B_T^2 . \sin\vartheta . \delta\vartheta . /4\pi \ . \ \text{or} \quad \delta E \approx B_T . \rho g\Delta/B_z \ , \qquad (4)$$

after substituting for $\sin\vartheta . \delta\vartheta$ from equation 3.

Equation 4 gives an estimate for the free energy density of the tension free field. For purposes of order of magnitude estimation, we will assume that the lateral gradient of B_z equals the vertical gradient of B_T (this is strictly true for a potential field and is a good approximation for a force free field near the polarity inversion line). Using this assumption in equation 4, we have

$$\delta E \approx \rho g\Lambda_B \ . \qquad (5)$$

For order of magnitude estimates one can also assume that Λ_B equals the typical size of a bipolar active region which is $\approx 10^9$ cm. The total energy can now be written as

$$\delta\mathcal{E} \approx A.(h_{chr}n_{chr} + h_{cor}n_{cor})m_H g\Lambda_B \ . \qquad (6)$$

Assuming $A \approx 10^{19}$ cm^2, $m_H = 1.6\times10^{-24}$, $g \approx 2\times10^4$ cms^{-2}, we have $\delta\mathcal{E} \approx 10^{30}$ ergs, for $n_{chr} = 10^{14}$, and $h_{chr} \approx 10^8$ cm. For the sun, this energy is lower than the energy released in major flares, but is very similar to the energy released in the impulsive phase of typical flares. Thus the storage of energy in tension free fields can provide sufficient destabilisation via thermal convective instabilities to initiate the flare. The size of the flaring region in stellar atmospheres does not seem to be much different from that on the Sun (de Jager, *et.al.*, 1989). Thus, one cannot explain the frequent occurrence of white light flares in stars by invoking larger starspots. One clue is that the chromospheres of flare stars (dMe) are few orders of magnitude denser than normal chromospheres (Cram and Mullan, 1982). By assuming $n_{chr} \approx 10^{15}$ in equation 6, we obtain $\delta\mathcal{E} \approx 10^{31}$ ergs. In this case, there is much more energy available for destabilising the tension free fields and thus, a greater probability for producing major flares.

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