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Is a Sunspot in Static or Dynamic Equilibrium?

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Extended abstract

Sunspots have been studied ever since their discovery by Galileo, but the investigation of sunspot structure remains a current issue. The theoretician's ideal, isolated sunspot is rarely observed. However, most of the discussions about the stability and dynamics of sunspots are based on this ideal model. In what follows, we shall examine the evolution of a similar idealised model of a sunspot and comment on the implications of this study on the use of sunspots as tracers of subphotospheric dynamics.

To simplify matters, let us assume a sunspot where the vertical or z-component of the field varies with ρ direction as;

$$B_z = B_0 \exp(-\rho^2/L^2).$$

This component alone will produce a cylindrical spot model quite unlike what is generally observed. However, this cylindrical model can serve as an approximation for a sunspot when we consider a small height range of the spot. As can be seen later, this assumption is not central to the issue being discussed. Generally, any such model is considered to be in static equilibrium because the electrical resistivity of the plasma is very high, leading to diffusion times that are much larger than the life-time of the sunspot. In a recent paper Schrijver, C. J. *et al.* (1998) showed that reconnection events at the network boundary enhance the effective mean free path for magnetic field diffusion to 30000 km. They also note that the typical time between events is about 6 hours or roughly 20000 s. Thus the magnetic diffusivity η realised by this process is 10^{15} cm^2 s^{-1}. This diffusion cannot be ignored as can be seen in what follows.

The diffusion equation of the magnetic field can be written as:

$$\frac{\mathrm{d}}{\mathrm{d}t} B_z = \eta \frac{\mathrm{d}^2}{\mathrm{d}x^2} B_z.$$

For an initial field at $t = 0$, as given earlier, the time evolution turns out to be:

$$B_{z(t)} = B_0 \exp(-\rho^2/(L^2 + \eta t)).$$

For a sunspot of initial size of 30000 km, the time taken for doubling of its size by diffusion is roughly 6 hours. For smaller spots, it is smaller, scaling as the Square of the size. Actually, these estimates are conservative estimates, since the initial ρ-profile chosen was a gaussian. The effect would be more severe for a sharper

profile. Clearly then, diffusion cannot be ignored and a static sunspot is not physically realisable.

The way out of the apparent dilemma posed above is to have a spot in dynamic equilibrium. In this case, the diffusion is halted by a plasma flow that converges towards the spot. The surface flows like the Evershed flow, runs counter to such a requirement. It would seem therefore, that converging flows are beneath the surface. Recent work based on time distance seismology has indeed pointed towards such an inference. The sunspot thus seems to exist due to the effect of flows acting at and near the solar surface. Furthermore, the position of a sunspot is then decided by the location of such a flow pattern. The pattern can, in principle, move independent of the general plasma flow, which is basically solar rotation. Thus, the use of spots as tracers of subsurface rotation becomes debatable.

References

Schrijver, C. J. *et al.* 1998, *Nature,* **394,** 152.