THE SMALLEST OBSERVABLE ELEMENTS OF MAGNETIC FLUX

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Abstract. We have followed disappearing elements of magnetic flux to determine the smallest elements detectable with the Big Bear videomagnetograph. All the elements followed were disappearing through interaction with elements of opposite polarity. The last remaining visible segment of magnectic field of such features can be used to infer the total magnetic flux of these and other small flux elements visible on the magnetograms.

We used both photographic and digital videomagnetograms combining 4096 Zeeman frames made at Big Bear. Fifteen elements were measured near the vanishing point, in a 2–8 hr period. The minimum observable fluxes fall in the range of 1.0×10^{16} to 1.4×10^{17} Mx, and the apparent size of these elements is in the range of 1 to 9 square arc sec. The process of disappearance appears to be a smooth one. The smallest detectable elements of network field and ephemeral regions (ER) appear to be the same as the small intra-network (IN) field elements. The present limit is still instrumental; elements smaller than 1×10^{16} would not have been detected.

1. Introduction

A number of authors (Beckers and Schröter, 1968; Stenflo, 1973; and Zwaan, 1978) have discussed the strength of elements of photospheric magnetic fields and concluded that these are concentrated in discrete bundles of fairly strong (1000 G) flux. Spruit (1977) has developed detailed models for these small structures. This general picture is supported by the fact that improved magnetograms always reveal smaller and smaller individual elements and never a uniform background field. Because the existence of these strong small fields is only indirectly established, there have been attempts to measure the smallest possible flux elements.

Simon and Zirker (1974) used spectroscopic observations to find minimum field strengths in the range 100 G to 1000 G, and sizes larger than 1.5″ in the chromospheric network. These numbers correspond to 10^{18} Mx. Because of time and field limitations they could not really search for the 'smallest flux elements". In his review of the flux characteristics of small scale magnetic field on the quiet Sun, Harvey (1977) showed examples of the intranetwork (IN) fields, and measured their flux at 5×10^{16} Mx. It is not clear if Harvey was looking for the smallest features; more likely he was referring th the typical IN fields and could have reached smaller values.

In the present work we have utilized time sequences to search for and measure the smallest possible flux elements. Because of the difficulty of deciding if a marginal small element was real, we chose shrinking elements and followed them down to the smallest detectable size. The video technique has the advantage that (1) if we observe an element

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several times we know it is real and (2) if an element is shrinking we have a hope of finding it even smaller than it is now. The disadvantage of this technique is that it measures only the 'tip of the iceberg' if submergence is taking place; but it establishes the reality of measurements at this level, which may be imputed to other elements in the magnetograms. The fact of disappearance means that we really can't detect the flux if it decreases further.

The videomagnetograph at BBSO was built by Smithson and Leighton (Smithson, 1972). In 1979 it was rebuilt with a digital image processor, and in 1981 we improved the capability by installing RCA cameras with Nuvicon tubes, replacing the KDP crystal, and introducing computer programs permitting the accumulation of an almost unlimited number of frames. Introduction of a large storage disk permitted recording digital images, and the problem of calibration (using solar rotation Doppler images) has been worked out by Shi *et al.* (1985). In practice up to 4096 frames are accumulated, requiring 138 seconds of observation. The long integration time only slightly degrades resolution, because there is an enchancement effect with superposition of many elements. Under good seeing conditions, the sensitivity of the system steadily increases with number of frames, and the noise level of the 4096 frame magnetogram is arround 2 G. So although there is some distortion of strength and size, the total flux is still meaningful. The prinicpal noise sources are the vidicon, the A/D conversion, and image jitter. Sequences of such sensitive long integration videomagnetograms show that the disappearance of magnetic flux occurs frequently on the quiet Sun (Martin, 1983; Wang *et al.*, 1985). As we follow the disappearance process, we can watch flux elements shrink and determine the smallest observable flux elements.

We measured the magnetic flux of 15 of the last remaining visible segments of eight continuously shrinking magnetic features which appear continuously to cancel (by reconnection and submergence, we assume) with other magnetic features of opposite polarity during periods of 2–8 hr. Although ERs, network, and IN regions show successively weaker fields, elements of the smallest size were found in each as the magnetic knots shrank. That this is not a question of changing VMG sensitivity is attested by the appearance of constant or growing flux in other magnetic elements, and Doppler calibration of digital magnetograms a few hours apart.

2. The Identification of Smallest Visible Flux Elements

Under excellent seeing conditions on 4 September 1983, 2048 and 4096 frame videomagnetograms of the quiet Sun were obtained at Big Bear Solar Observatory. Since a number of disk areas were being studied, the interval between frames for our area was typically 30 min. The digital magnetograms are normally converted to analog form and recorded on film; at 22 : 51 UT and 00 : 27 UT two series of digital magnetograms with a range of integration times were recorded on disk and calibrated. The analog films are used to follow the disappearing elements and the two calibrated digital series, for the quantitative measurements. Thus the size of the regions is limited by their strength at the times of the two digital series. To calibrate the magnetograms we convert to Doppler