VECTOR MAGNETIC FIELD OBSERVATIONS OF FLUX TUBE EMERGENCE

Schmieder B.1, Aulanier G.1, Pariat E.1, Georgoulis M.K.2, Rust D.M.2, and Bernasconi P.N.2
1 Observatoire de Paris, LESIA, 92195 Meudon Cedex Principal, France
2 JHU/Applied Physics Laboratory, 11100 John Hopkins Road, Laurel MD 20723-6099, USA

ABSTRACT

With Flare Genesis Experiment (FGE), a balloon borne Observatory high spatial and temporal resolution vector magnetograms have been obtained in an emerging active region. The comparison of the observations (FGE and TRACE) with a linear force-free field analysis of the region shows where the region is non-force-free. An analysis of the magnetic topology furnishes insights into the existence of “bald patches” regions (BPs are regions where the vector field is tangential to the boundary (photosphere) along an inversion line). Magnetic reconnection is possible and local heating of the chromosphere is predicted near the BPs. Ellerman bombs (EBs) were found to coincide with few BPs computed from a linear force-free extrapolation of the observed longitudinal field. But when the actual observations of transverse fields were used to identify BPs, then the correspondence with EB positions improved significantly. We conclude that linear force-free extrapolations must be done with the true observed vertical fields, which require the measurement of the three components of the magnetic field.

Key words: Solar magnetic field, Ellerman Bombs.

1. OBSERVATIONS

1.1. Launch of the Flare Genesis Telescope in Antarctica

Flare Genesis Experiment (FGE) and launch in January 10-27 2000. FGE consists of an 80 cm Cassegrain telescope with an F/1.5 ultra-low expansion glass primary mirror and a crystalline silicon secondary mirror. A helium-filled balloon carried the FGE to an altitude of 37 km (Bernasconi et al. 2000, 2001).

1.2. Magnetogram and Hα image

The observations were obtained through a polarization analyser unit (two liquid-crystal variable retarders and a linear polarizing filter, a selection of 1.25 Å order-isolation filters, a 0.16 Å tunable Fabry-Pérot etalon filter and refractive optics to present a 160 ″ diameter section of the sun to a 1024×1024-pixel CCD camera. The plate scale is 0.091 ″ per pixel and the image quality was around 0.5 ″. We made observations of all the four Stokes parameters in the red and blue wings of the Ca I line at 6122.2 Å. Unpolarized observations were obtained at 0.8 Å in the blue wing of the Hα line at 6562.8 Å. During the 3.5 h of observations (15:50-19:16 UT), we obtained 55 vector magnetograms, 28 Dopplergrams of the photosphere and 28 Hα -0.8 Å filtergrams of the chromosphere.

Active region NOAA 8844 consisted of two stable sunspots on January 24 th and rapid growth of emerging flux in the middle of the AR were observed early on the 25 th, characterized by fast moving mixed polarities with horizontal flow of 0.3 -0.8 km s⁻¹ (Bernasconi et al. 2002).

FGE Hα - 0.8 Å observations and longitudinal magnetogram (590 × 590 pixels with a 0.18 ″ pixel size) inserted in a large IVM magnetogram (Hawaiii). From comparison of FGE and IVM magnetograms we have derived calibration factors for FGE. Note the dark fibrils in Hα blue wing (left panel) corresponding to rising motions of an arch-filament system over the emerging flux and bright points so-called Ellerman bombs (Georgoulis et al. 2002).

1.3. Space Observations

The FGE data of NOAA 8844 AR, located at 5⁰N30⁰W on January 25 2000, were coordinated with other instruments: on the ground with the IVM of Hawaii and in space with SOHO/MDI, Yohkoh/SXT and TRACE. SXT observed the AR 8844 with the AlMg filter between 15:11 and 16:01 and between 16:48 and 17:43 UT with a partial
field-of-view (128 × 128 pixels), with a pixel size of 2.4 ″ and a cadence of 60 sec. TRACE provided between 17:00 and 19:00 UT high cadence filtergrams in Fe IX/Fe X 171 Å and Fe XII 195 Å lines (80 sec), filtergrams in the broadband pass around 1600 Å and few white light images used to coalign TRACE images with FGE Ca I intensity maps. Analysing 13 TRACE frames obtained simultaneously with FGE Hα wing frames we find that more than 50 percent of bright 1600 Å emission kernels coincide with Ellerman bombs (Georgoulis et al 2002).

While SXT shows the top of low hot loops (around 4×10⁶ K) over the active region and a subflare at 17:04 UT (Fig. 1), TRACE images point out the existence of thin loops (max (Te) = 1.2 10⁶K, max (EM) = 8×10²⁶ G/cm³) and knots of denser material flowing along the loops (Fig. 1).

2. LINEAR FORCE-FREE FIELD EXTRAPOLATION

2.1. Method

The magnetic field is frozen into the plasma almost everywhere in solar active regions. We assume that:

\[ \nabla \times \vec{B} = \alpha \vec{B} \]

The current is aligned with \( \vec{B} \), so there are no Lorentz forces.

Using a lff extrapolation code, we obtain magnetic field lines over the AR 8844. The field lines that fit best with TRACE coronal loops give a \( \alpha \) value for the region (Fig. 2).

2.2. Definition of Bald patches

Separatrix surfaces are locations where current layers can be formed. Classically a separatrix is a 3D surface defined by all the field lines passing through one null point. If there are no null points another class of separatrix can be considered: then they are defined by the field lines passing through “bald patches” (BPs). BPs are regions where the vector field is tangent to the boundary (photosphere) along an inversion line. magnetic reconnection is plausible, so local heating of the chromosphere would be expected near bald patches.

BP = dip in a field line
At \( z = 0 \) and where \( B_z = 0 \) BPs are defined by

\[ (\vec{B} \cdot \nabla) \vec{B} > 0. \]

2.3. Association of BPs and Ellerman bombs

The extrapolation was done with two different inputs:

1. \( B_{trans} \) was calculated from the lff equations using observed \( \vec{B}_{long} \). Then, positions of bald patches (BPs) were found in the computed fields. Only a few BPs are associated with Ellerman bombs in mixed polarity regions, in the trailing spot only (Fig. 2).
Figure 2. “Bald patches” and associated magnetic field lines overlaid on Hα map (left panel) and on the FGE longitudinal magnetogram in gray scale (right panel) at 18:00 UT on January 25 2000. The field lines are computed by linear force-free field extrapolations with $\alpha = 0.01 \, \text{Mm}^{-1}$ from FGE magnetogram, overlying Hα image. North is up.

Figure 3. Observed “Bald Patches” overlaid on the Hα map (left panel) and on FGE magnetogram (right panel) with overlaid contours of $B_{\text{long}}$ (threshold of $B_{\text{trans}} = 200 \, \text{G}$) at 18:00 UT. The bald patches are represented by the black circles. They fit well with the Ellerman Bombs: bright features in the Hα map. North is up.
2. On the other hand, BPs can be directly calculated from the full vector field observations (Bx, By, Bz). In that case, we found that BPs in all the regions are well associated with Ellerman bombs, including in the leading spot region, where B_long > 0 but in which some small Bz < 0 regions exist (Figs. 3 and 4).

3. Importance of Btrans: From the comparison of the calculated BPs (from lff extrapolations) with the observations, we conclude that it is very important to have a true Btrans, not force-free derived values, to find BPs.

3. CONCLUSION

The fields in AR 8844, with its central emerging flux region, were not force-free, even though the coronal loops seem to fit a linear force-free field configuration with an α = 0.01 Mm−1. When bald patches were derived from vector magnetic field observations, we found that Ellermans bombs often occurred at BP sites. The transverse field has to be considered to define the fields near activity sites and not only the longitudinal field (Fig. 5).

In the future, we will re-calculate lff extrapolations from observed Bz maps, which should provide not only the BP locations as the vector magnetograms do, but also the field connectivity. Thus we expect to calculate the 3D separatrices associated to BPs, along which EBs may also occur due to current intensification along them. This may help in interpreting the observed EBs which are not co-spatial with BPs.

References: