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A Detailed Analysis of an Ephemeral Region

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Abstract. In order to improve the understanding of the process of emergence of magnetic flux on the solar surface, we studied the temporal evolution of an ephemeral region using *Advanced Stokes Polarimeter* data. We adopted two different approaches: first, we used a Milne-Eddington inversion to obtain mean parameters of the emerging bipole magnetic configuration. Then, we considered the full radiative transfer equation, and we studied the trend of all the previous parameters as a function of the optical depth τ. We pointed out peculiar flows, such as an initial upflow of 1.5 km s^{-1} where the zenith angle is essentially horizontal, and downflows decreasing in time in footpoints, characterized by a vertical field. These results seem to confirm the emerging bipole topology, due to magnetic flux tube emergence. The results obtained with this inversion confirm the structure found with Milne-Eddington code. However we found regions in which the presence of two distinct magnetic components is highly significant. It also seems very interesting the trend of the temperature with optical depth: the plasma temperature appears to grow up in the high photosphere above the emerging bipole.

Key words. Sun: activity - Sun: atmosphere - Sun: magnetic fields - radiative transfer - MHD

1. Introduction

In the framework of emergence of magnetic flux on solar surface, we deal with the problem of emergence of ephemeral regions, active region with lifetime of the order of the day (Harvey & Martin 1973), from which the term "ephemeral", short-lived. These ephemeral active regions have total magnetic flux included between $\sim 5 \times 10^{17}$ Mx and 5×10^{19} Mx. They are clear features of emergence of bipolar structures on solar surface, identified as magnetic flux tubes which rise through the convective zone and emerge into photosphere, due to magnetic buoyancy. Although ephemeral regions have been known since a few decades, only high resolution observations during last years allowed their deep study. In this work, we develop a full detailed analysis of an emerging ephemeral region during the early phases

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of emergence process. That has been done with spectropolarimetrical data of *Advanced Stokes Polarimeter* (Elmore et al. 1992), with a temporal series acquired along the Fe I lines at 6301.5 Å and 6302.5 Å, close to the center of the solar disk (Lites et al. 1998). We adopted two different inversion techniques: Milne-Eddington (*M-E*) inversion, based on the Unno-Rachkovsky solution of radiative transfer equation, which is able to provide mean parameters of magnetic field along the line of sight, such as magnetic field strength B and zenith angle γ (Skumanich & Lites 1987), and *SIR* (Stokes Inversion based on Response functions) code, based on full radiative transfer equation, which is ideal to analyse the spatial three-dimensional structure of an emerging flux region and its physical parameters with respect to optical depth τ (Ruiz Cobo & del Toro Iniesta 1992).

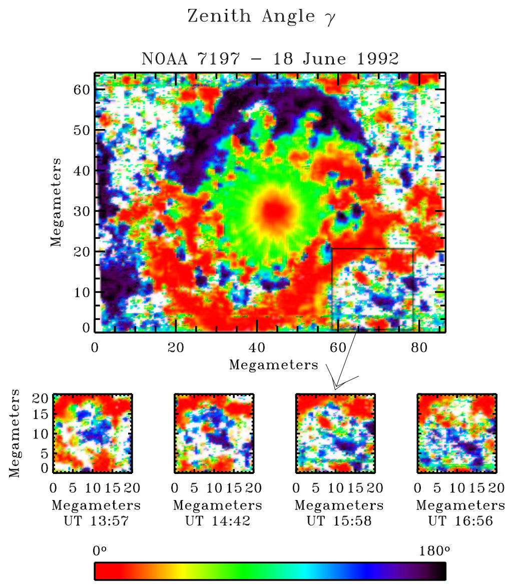

Fig. 1. Maps of zenith angle γ, retrieved by M-E in four frames. Only pixels with total polarization signal larger than 1.3% have been inverted: the bipolar structure is well recognizable.

2. M-E inversion

M-E inversion points out that the ephemeral region possess a classical bipolar structure (see fig. 1): the central parts of the bipole, said emergence zone, have horizontal zenith angle, i.e. $60° < \gamma < 120°$, weak field strength, lower than 600 Gauss, filling factor higher than elsewhere in the region, and upflow. Thus, it may represent the emerging top of the loop, as shown by Lites et al. (1998). Footpoints have vertical zenith angle, i.e. $\gamma < 60°$ or $> 120°$, high field strength and downflows. We are not able to recognize the presence of magnetic twist in the ephemeral region.

The morphology agrees with what theoretical models predict about emerging flux tubes structure. But we notice a distortion of the tube: f footpoint appears to be more concentrated than the p one, this latter appears to be less vertical, with lower field strength than the former (see eg. Caligari et al. (1995)), while a *cross-correlation* analysis points out that the p footpoint moves faster westward than the f one eastward. For what concerns the dynamics of the emergence, we obtained rising speed values through geometrical and spectroscopical estimates. The most reliable values, whose trend agrees with spectroscopical estimate, are deduced from an asymmetric model, with f footpoint more vertical than the p one. We notice that upflow decreases as ephemeral region emerges. Downflow in footpoints shows a decrease, due to mass loss in the loop during the emergence and to fall motions along its legs. It appears to be a systematic asymmetry in downflow intensity in the footpoints: in the f one, downflow is always stronger than in p footpoint. This difference could be due to loop distortion and to the distinct inclination of footpoints along the line of sight, agreeing with Spadaro et al. (2004).

3. SIR inversion

SIR inversion gave the possibility to analyse the effective spatial structure of the ephemeral region, by using one or two magnetic components: we found results which in general confirm the ones obtained with M-E, and, in two-component inversions, M-E values are represented in one of the components. Several tests show the reliability of values retrieved by SIR and the capability to reproduce peculiar pro-

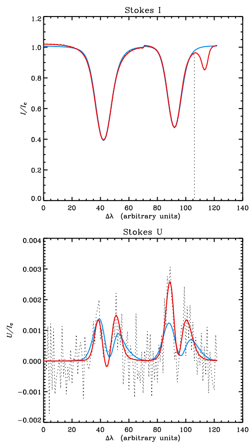

Fig. 2. Results of the inversion of profiles with SIR with one (blue line) and two (red line) magnetic components: it is noticeable the necessity of two components to match a reliable fit.

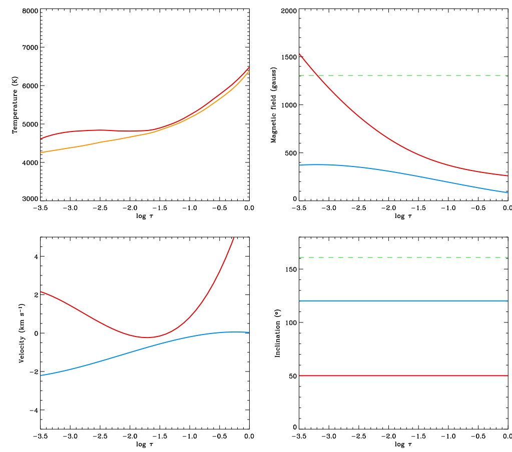

Fig. 3. Physical parameters retrieved by SIR: temperature, magnetic field strength, zenith angle, and velocity of plasma. Red and blue lines represent the two magnetic components, orange line the HSRA (Gingerich et al. 1971) model trend. We notice the presence of two magnetic components with positive and negative flux at the same time, one with upflow, the other one with downflow. Green line represents M-E result.

files only by adopting two magnetic components, as we show in fig. 2. Through SIR we noticed that some points inverted with two components have a positive polarity before hidden, whose signal comes from a magnetic field deeper in photosphere than the field which originates the signal with negative polarity. We find an asymmetry of the flux rope consisting with the one described previoulsy, an the presence of an upflow component (see fig. 3), but we tried unsuccessfully to study the twist at different values of τ.

It is remarkable the peculiar trend of temperature with respect to optical depth in the early phase of emergence: it shows a minimum and rises again. It could be due to magnetic interactions between the NOAA 7197 and this bipole: emerging field lines could reconnect with *canopy* lines and give rise to heating in the highest region of the photospheric layers.

4. Conclusions

This work represents a first detailed analysis of the parameters of an ephemeral region in photosphere. Next developments in research on this topic should provide the availability of a wide sample of ephemeral regions, acquired in different period of activity solar cycle, with high spatial, spectral and temporal resolution, and should follow bipole emergence at different atmospheric levels.

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