The use of spectro-polarimeter measurements to determine the plasma heating

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Abstract

We present the possible use of spectro-polarimeter measurements of Solar-B on similar set of data recorded with La Palma Stokes Polarimeter attached to the Swedish Vacuum Solar Telescope. The stratification over the solar atmosphere of different physical parameters is retrieved from these data using the Stokes Inversion based on Response functions. Coming out from the stratification of the magnetic field strength and orientation of the magnetic field vector, we derive the vertical component of electric current density. We also found spatial and height correlation between the temperature enhancement and increase of electric current density, this could be caused by the energy dissipation stored in the magnetic field configuration.

Observations

On May 13, 2000, we observed an irregular sunspot in active region NOAA 8990 with La Palma Stokes Polarimeter (LPSP) attached to the Swedish Vacuum Solar Telescope.
The spot was located near the disc center, at heliocentric position 14° N and 17° W. The white light image of this active region is shown in Fig. 1. Two areas (1, 2) were scanned in the magnetically sensitive lines Fe I 630.15 nm (Landé factor $g = 1.67$) and Fe I 630.25 nm ($g = 2.5$).
The size of scanned areas is 14.5” × 19”.

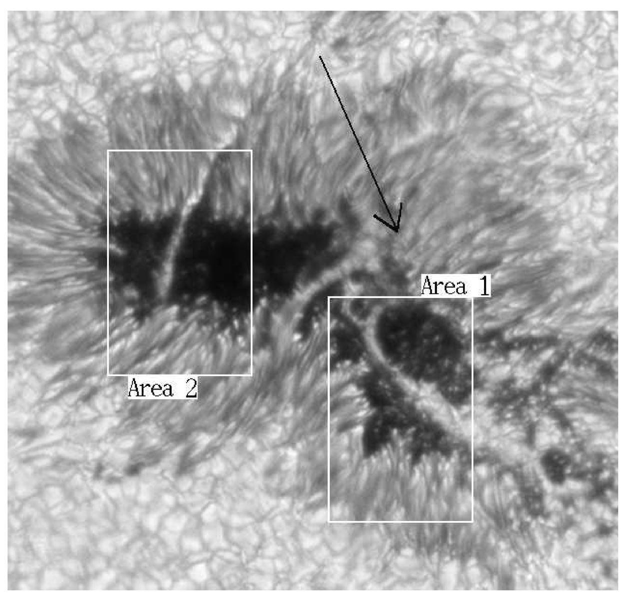

Figure 1: White light image of active region NOAA 8990 with marked areas under study. The arrow points to the north direction.

Comparison of LPSP and Solar-B spectro-polarimeter

In the following table we compare the basic characteristics of used spectro-polarimeter (LPSP) and Solar-B SP. The main advantage of Solar-B is that the spatial resolution is not degraded by seeing. Moreover, the absence of stray-light in observed profiles improve the accuracy of the inversion process.

	Solar-B SP	**LPSP**
Maximal FoV	164” × 320”	60” × 60”
Spectral resolution	30 mA	40 mA
Width of slit	0.16”	0.32”
Step of slit	0.16”	0.24”
Spatial resolution	0.25”	0.7”

Inversion method

We used the inversion code SIR (Stokes Inversion based on Response functions) developed at the Instituto de Astrofísica de Canarias by Ruiz Cobo and del Toro Iniesta [1]. It is a one-dimensional code working under the assumption of local thermodynamical equilibrium (LTE). The inversion code gives the stratification of temperature, magnetic field strength, inclination, azimuth, and other plasma parameters [2].
One of the input parameters is the stray-light profile [2]. We used the stray-light coming from the quiet sun (it means no stray light in Q, U and V), but we also made some tests with the stray light profiles mixed of the quiet-sun profiles and the umbral ones. We found that the increase of the fraction of the umbral component in the stray-light profile causes the decrease of magnetic field strength at almost all heights (Fig. 3, stratification of $|B|$, blue line corresponds to the stray-light mixed of 20% of the umbral profile and 80% of the profile taken from the quiet sun). The absence of the stray-light profile in the case of satellite measurements eliminates one of the ambiguities of inversion techniques.
Typical examples of Stokes profiles observed in the light bridge are shown in Fig. 2. In Fig. 3 there are plotted the resulting stratifications of temperature and magnetic field strength for these profiles.

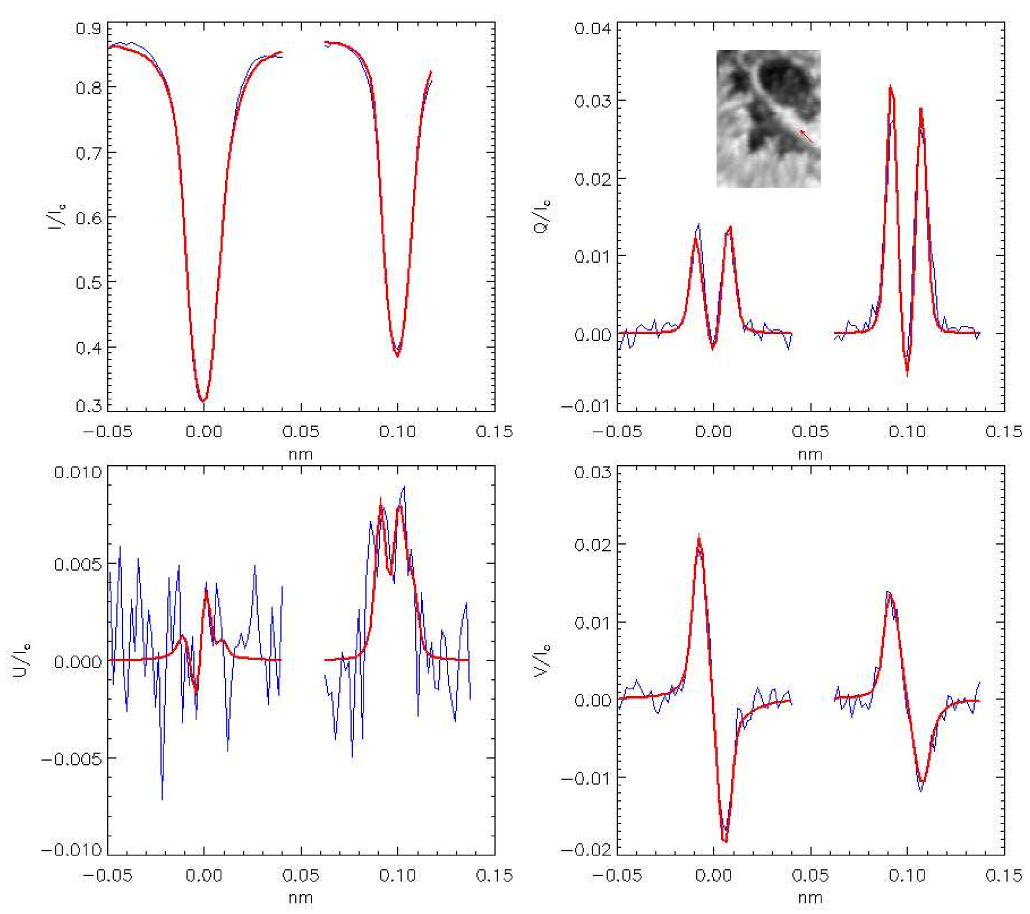

Figure 2: I, Q, U and V profiles of Fe I line 6301.5 Å (left) and Fe I line 6302.5 Å (right). The blue line corresponds to the observed profile and the red line to the synthetic profile computed by SIR. The arrow in the white light image points to the location of origin, a broad part of light bridge in Area 1.

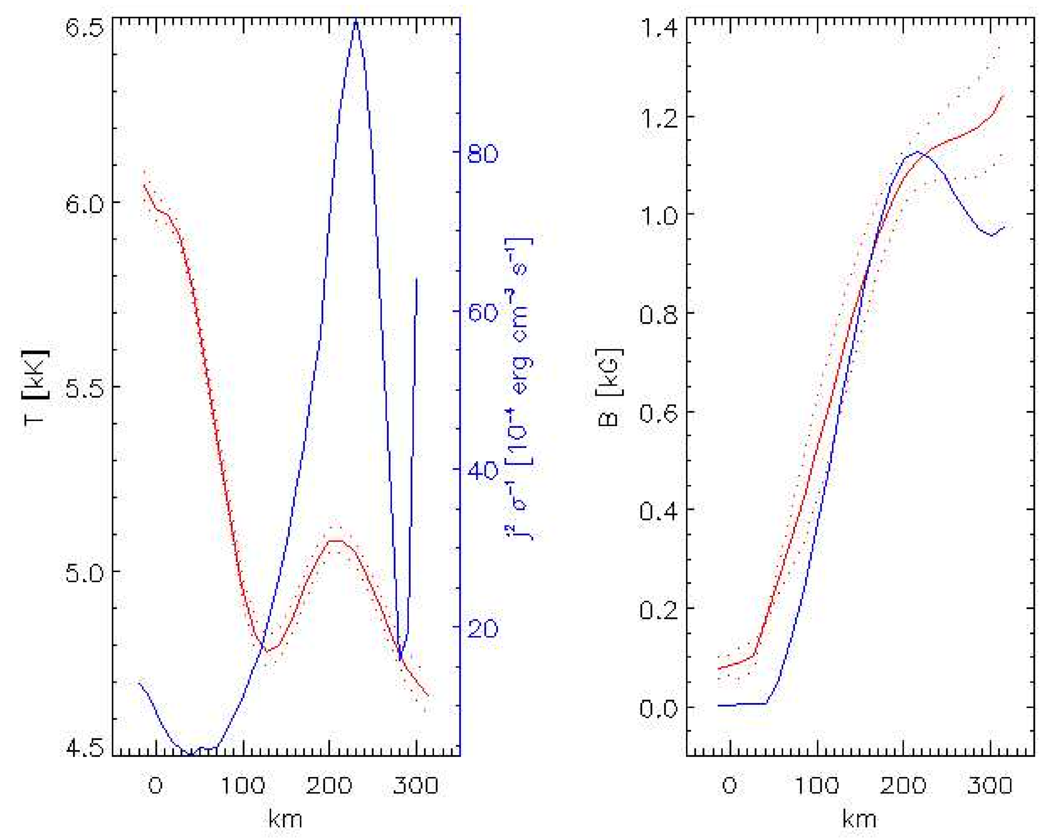

Figure 3: The stratification of T and $|B|$ (solid red lines) and the range of errors (dotted red lines). Blue line in the temperature plot corresponds to the ohmic dissipation. The blue line in the B stratification represents the possible stratification of $|B|$ if we use the stray-light profile partly coming from the surrounding umbra.

Current density and corresponding plasma heating

In Fig. 3 we see the increase of temperature around 200 km. Such temperature bumps are present in 82% of light bridge points. Temperature is the most precisely determined plasma parameter and we believe that these temperature increases are real. A possible reason of their formation could be the plasma heating caused by the energy dissipation stored in the magnetic field configuration.
From the individual stratifications of $|B|$, inclination and azimuth we derived the x and y component of magnetic field and compute the z component of current density (J_z) [3]. The resulting maps of J_z are shown in Fig. 4, where higher current density in light bridges is clearly recognisable. In Fig. 5 we show the resulting temperature maps overlaid with contours of current densities. In the case of broad light bridge (upper maps) we see the spatial correspondence between higher temperature and higher J_z. This also results in the spatial correspondence between the ohmic dissipation and temperature, because the energy dissipation is proportional to J_z^2. The height correlation between these parameters is shown in Fig. 3 (temperature stratification, blue line). We compared found values of ohmic dissipation with the net radiation [4] to estimate the possible influence of the magnetic field energy dissipation on the temperature increase. The difference is around 6 orders of magnitude in the light bridge regions and it seems to be evident that the temperature increase cannot be explained by the ohmic dissipation. However, there are two facts that heavily influence the resulting value of ohmic dissipation. First, we computed only the z component of current density and did not take into account the other two components. Second, the current density is highly dependent on spatial resolution and therefore the values of J_z derived from our observations are probably underestimated.

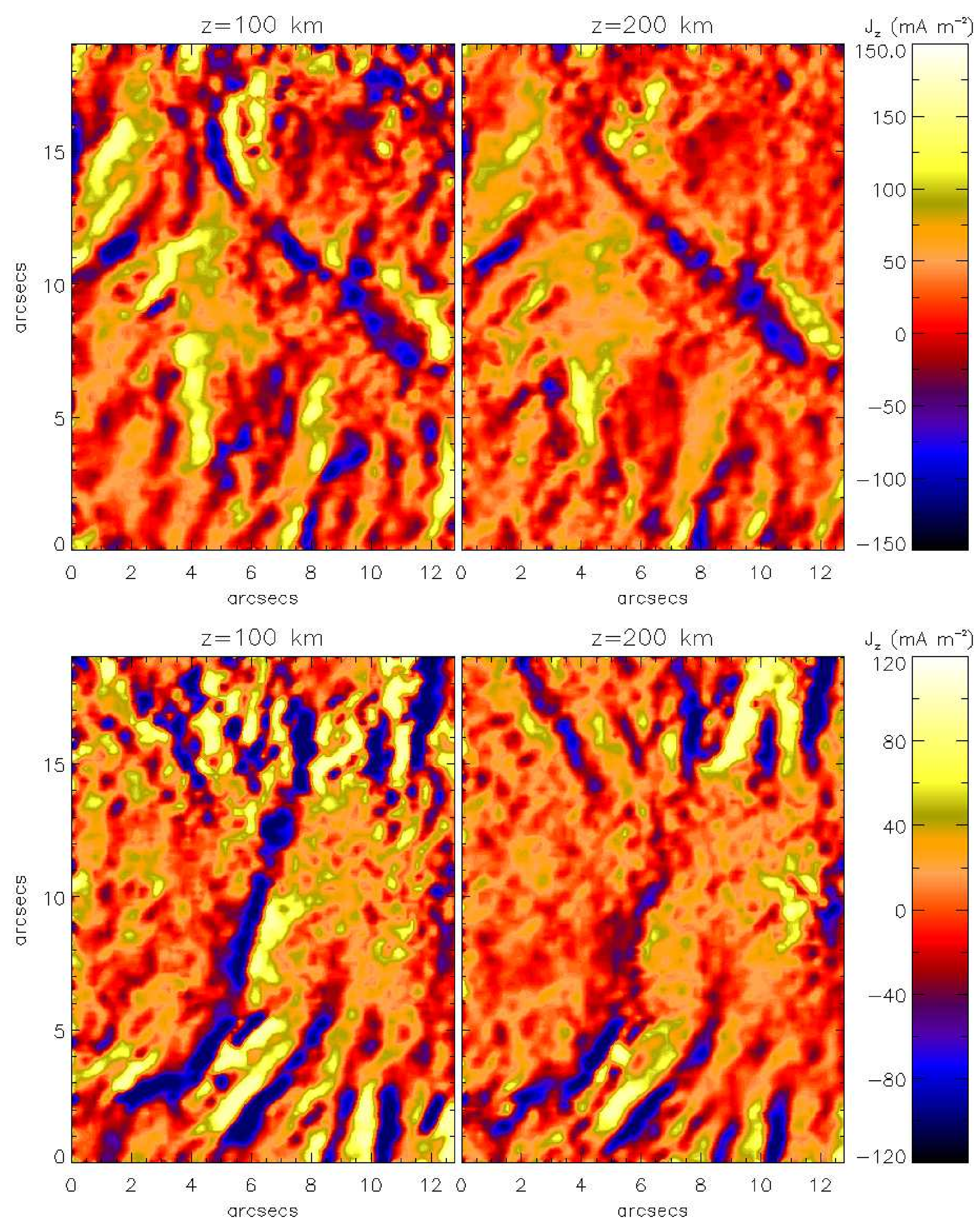

Figure 4: Resulting maps of current density J_z in Area 1 (top) and Area 2 (bottom).

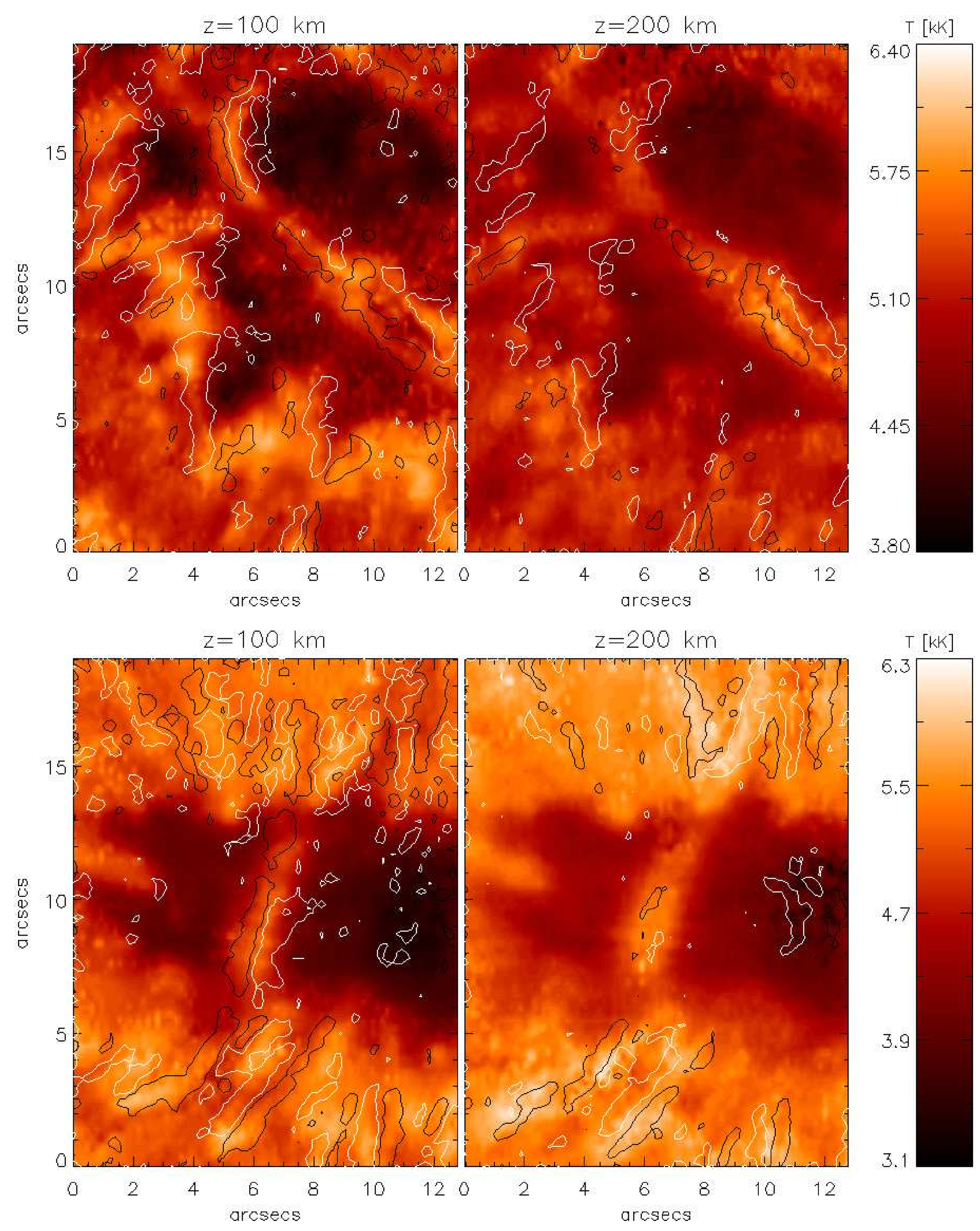

Figure 5: Resulting maps of temperature with contours of current density. Black contour corresponds to -65 mA m^{-2}, white to 65 mA m^{-2}.

Conclusions

The resulting temperature and magnetic field vector orientation is in a good coincidence with the expected behaviour in the umbra, penumbra and light bridges. Considering these facts, we can trust the results coming from the inversion code.
The increase of current densities in light bridges is caused by the magnetic field shear between the field-free plasma in light bridge and magnetic plasma in the surrounding umbra. The values of ohmic dissipation computed from J_z and plasma conductivity are too small to explain the observed enhancement of temperature around $z = 100$ and 200 km in regions with higher current density. Nevertheless, the spatial and height correlation between these parameters is evident. The values of J_z derived from the observations made by the Solar-B spectro-polarimeter would be probably higher. These measurements could confirm the expected trend of increasing J_z with improving spatial resolution and confirm possible existence of ohmic dissipation in light bridges.

References

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