Magnetic Field Structures in a Facular Region Observed by THEMIS and Hinode

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Abstract The main objective of this paper is to build and compare vector magnetic maps obtained by two spectral polarimeters, i.e. THEMIS/MTR and Hinode SOT/SP, using two inversion codes (UNNOFIT and MELANIE) based on the Milne–Eddington solar atmosphere model. To this end, we used observations of a facular region within active region NOAA 10996 on 23 May 2008, and found consistent results concerning the field strength, azimuth and inclination distributions. Because SOT/SP is free from the seeing effect and has better spatial resolution, we were able to resolve small magnetic polarities with sizes of 1″ to 2″, and we could detect strong horizontal magnetic fields, which converge or diverge in negative or positive facular polarities. These findings support models which suggest the existence of small vertical flux tube bundles in faculae. A new method is proposed to get the relative formation heights of the multi-lines observed by MTR assuming the validity of a flux tube model for the faculae. We found that the Fe I 6302.5 Å line forms at a greater atmospheric height than the Fe I 5250.2 Å line.

Keywords Active regions, structure · Magnetic fields, photosphere · Polarization, optical

1. Introduction

Faculae are bright plages observed in Hα or photospheric lines. They are considered as magnetized regions constituted of a bundle of thin vertical flux tubes with a magnetic field
strength of thousands of gauss and a size of tens to hundreds of kilometers (Zwaan, 1987). Similar values for field strength and size of the flux tubes have been found by analyzing the ratio of Stokes $V$ signals in the Fe I 5250.2 Å, Fe I 5247.1 Å, and Fe I 5232.9 Å lines, for a spatially unresolved photospheric network (Stenflo, 1973). The flux tubes are located at the boundaries of granules and bundled by the convection flow. Since the pressure of the solar atmosphere decreases with height, the tubes expand and the magnetic field strengths decrease to compensate the pressure decrease. The network field expands rapidly with height and forms a canopy above the internetwork region. Similarly, the faculae would be bundles of flux tubes expanding with height.

In order to derive the three-dimensional (3D) magnetic structure of these features, we require multi-line spectral polarimetry. On the other hand, to resolve the fine structure, we require high spatial resolution. The French-Italian ground-based solar telescope THEMIS (Télescope Héliographique pour l’Etude du Magnétisme et des Instabilités Solaires) on the Canary Islands (López Ariste, Rayrole, and Semel, 2000; Bommier et al., 2007) and the Japanese space borne satellite Hinode (Kosugi et al., 2007) provide this ability. THEMIS is designed to be free from the instrumental polarization, since the polarization analyzer is located at the primary focus. It is also characterized by the multi-line spectroscopy capability in the MTR (Multi-Raies) grid mode that ensures the best co-spatiality. The beam exchange technique of MTR increases the polarimetric accuracy as the flat field errors are minimized. Solar Optical Telescope (SOT) aboard the Hinode spacecraft is not affected by the Earth’s atmospheric seeing effect. It observes diffraction limited images with 0.2″ – 0.3″ resolution by its 50 cm aperture optical telescope. The Spectral Polarimeter (SP) behind SOT observes the full Stokes profiles of two magnetically sensitive lines Fe I 6301.5 Å and Fe I 6302.5 Å (Ichimoto et al., 2008; Shimizu et al., 2008; Suematsu et al., 2008; Tsuneta et al., 2008). With its high performance, breakthroughs in different topics related to photospheric fields have been obtained by SOT: the detection of horizontal fields over granules and the hidden turbulent magnetic flux (Lites et al., 2007), the birth of small flux tubes with kilo-gauss field strength (Nagata et al., 2008), and the discovery of transient horizontal magnetic fields in quiet sun (Ishikawa et al., 2008).

The aim of this paper is:

1) To demonstrate that the two spectral polarimeters THEMIS/MTR and Hinode SOT/SP, and the two Stokes profile inversion codes give consistent results.

2) To study the magnetic structure of faculae.

We observe a facular region, build and compare vector magnetic fields using the full Stokes profiles of multi spectral lines observed by two spectral polarimeters (MTR and SOT/SP) and fitted by two inversion codes. We find concentrations of magnetic flux with converging and diverging transverse field vectors in high angular resolution magnetograms observed by SOT/SP. Finally, we use a flux tube model to get a qualitative view on the formation heights of two Fe I lines. The multi-line capability of THEMIS/MTR and the high angular resolution of SOT/SP complement each other in this study. The description of the observations and the methods of data analysis are given in Section 2. The results are presented in Section 3. We discuss the magnetic field gradient according to the flux tube model in Section 4. The conclusions are drawn in Section 5.