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# Validation of the PFSS coronal magnetic field model through UVCS/SOHO synoptic observations

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**Abstract.** SOHO/UVCS coronal synoptic maps of spectral line intensities may represent a powerful means to obtain information on the short and long term coronal evolution. They monitor trends over the solar cycle of the physical properties of the corona and allow the study of the variation of large scale structures. They also represent a unique opportunity for validating coronal magnetic field models obtained extrapolating photospheric measurements. The UVCS instrument aboard SOHO provides, for the first time, long time series of data for the UV coronal intensities from 1.5 to 3.0 $R_\odot$. The UVCS observations, performed almost daily from April 1996 to the present day, cover more than an entire solar cycle, and allow for a reconstruction of off-limb synoptic maps that can be used to compare and validate different coronal magnetic field models. In this work, focussed on the minimum of solar activity observed in the 1996, we compare the heliospheric neutral line position obtained from the Potential Field Source Surface (PFSS) model with the position of the maximum of intensity of the H I Ly$\alpha$ spectral line observed by UVCS at the heliocentric distance of 2.5 $R_\odot$. By comparing the UVCS observations with the theoretical neutral line positions, obtained with the PFSS model with varying the source surface distance, we infer that the source surface in PFSS models should be actually positioned at higher distance than the canonical 2.5 $R_\odot$ and possibly at lower distance than about 3.25 $R_\odot$.

**Key words.** Solar Physics – PFSS model – SOHO – UVCS

## 1. Introduction

It has been observed that the large-scale geometry of the coronal magnetic field plays an important role in the brightness distribution of the white-light corona and in the intensity distributions of the UV corona (e.g., Woo et al. 2005). The oppositely directed magnetic fields of the northern and southern hemispheres and the flow of the fast solar wind from the north and south polar coronal holes divide the heliospheric plasma in two regions, with opposite polarity. These two regions are separated by a current sheet, which is a neutral surface of symmetry for propagation of heliospheric plasma. This dipolar configuration was particularly evident at the time of the minimum of solar activity of the solar cycle 23. Even during solar minimum conditions, however, there are also contributions from low-order multipole fields whose importance decreases with height (e.g., Mancuso & Garzelli 2007).

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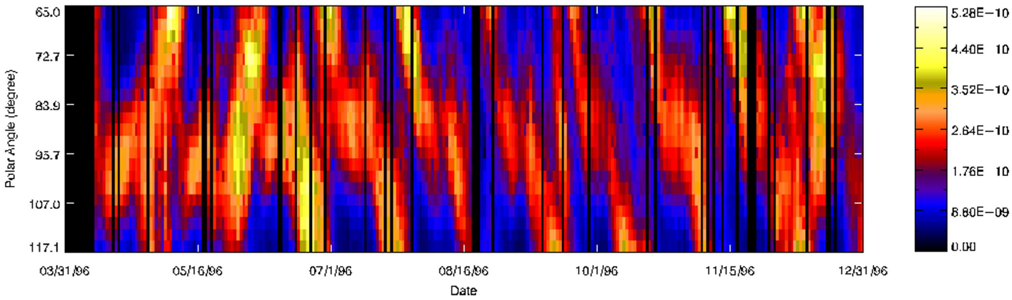


**Fig. 1.** H I Ly$\alpha$ (121.6 nm) intensity synoptic map from 1996 April 1st to December 31st obtained by interpolating the UVCS slit observations at 2.5 $R_\odot$.

In this paper, we reconstruct the coronal H I Ly$\alpha$ intensity synoptic map around the East and West equatorial region by interpolating the UVCS data at different coronal heights to obtain the time series at the fixed distance of 2.5 $R_\odot$ (see Figure 1). Then we apply a $\chi^2$ goodness-of-fit to the H I Ly$\alpha$ peak intensity positions and neutral line positions as obtained with the PFSS models by varying, over a range of heliocentric distances, the theoretical source surface radius, $R_{ss}$, which is typically (but arbitrarily) set at 2.5 $R_\odot$. This comparison allows to define the best source surface position for matching the model and the observations.

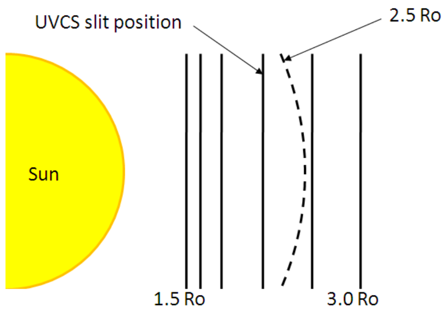


**Fig. 2.** Observed distances and relative positions of the UVCS slit associated to the synoptic program during the period under study. The curved dashed line represents the plane-of-the-sky section of a spherical surface at 2.5 $R_\odot$ over which the H I Ly$\alpha$ intensities have been interpolated by means of a power law function.

## 2. The PFSS model

The PFSS model (Altschuler & Newkirk 1969; Schatten et al. 1969) has been the first method that has allowed mapping the observed photospheric magnetic field into the corona. This model has been widely used for comparing the magnetic field topology with coronal and interplanetary solar wind density structures and for calculating the coronal holes and the heliospheric current sheet position. In fact, above the source surface, the magnetic field lines are assumed to be radial, and so the position of the heliospheric neutral line at any distance from the Sun can be inferred by radial extrapolation from the source surface. Applying the method described by Hoeksema and Scherrer (1984) (see also http://wso.stanford.edu/words/Description.ps) we implemented an IDL code to plot the PFSS synoptic charts and comparing the position of the theoretical neutral line with the one inferred from UVCS observations.

## 3. Data analisys

In this work, we analyzed spectral data acquired by the UVCS channel optimized for the observations of H I Ly$\alpha$ line at 121.6 nm. We have chosen to compare the observational data sets recorded in the first months of the SOHO mission from 1996 April 1st to December 31st, corresponding to Carrington Rotations from 1908 to 1918. We focus our investigation on the period of minimum of so-

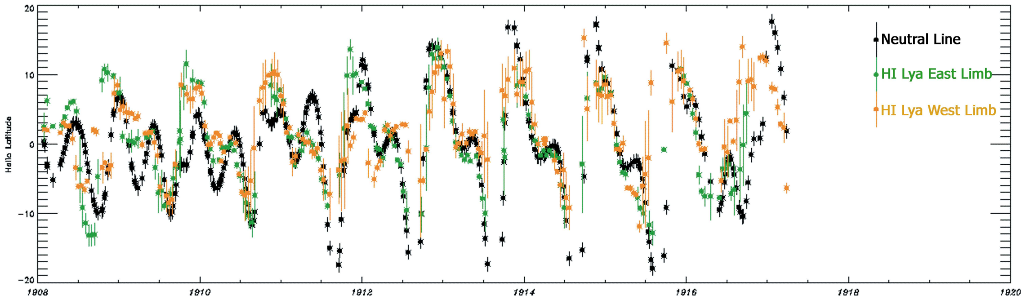


**Fig. 3.** PFSS neutral line position (black dots), at the heliocentric distance of 2.5 $R_\odot$, with the assumption of source surface radius at 2.9 $R_\odot$ compared with the position of the intensity peak of the H I Ly$\alpha$ line obtained for a spherical surface at the same distance (2.5 $R_\odot$) by the UVCS observations at East (green dots) and West (orange dots) limb.

| $R_{ss}$ ($R_\odot$) | $\chi^2_\nu$ |
|---|---|
| 2.00 | 37.346 |
| 2.25 | 23.916 |
| 2.50 | 17.754 |
| 2.60 | 17.228 |
| 2.70 | 15.977 |
| 2.75 | 15.611 |
| 2.80 | 15.490 |
| 2.90 | 14.878 |
| 3.00 | 14.474 |
| 3.10 | 14.164 |
| 3.20 | 14.802 |
| 3.25 | 14.722 |
| 3.30 | 14.657 |
| 3.40 | 14.571 |
| 3.50 | 14.533 |
| 4.00 | 14.585 |
| 4.50 | 14.821 |
| 5.00 | 14.204 |

**Table 1.** Value of $\chi^2$ (see text) as a function of PFSS source surface radius ($R_{ss}$)

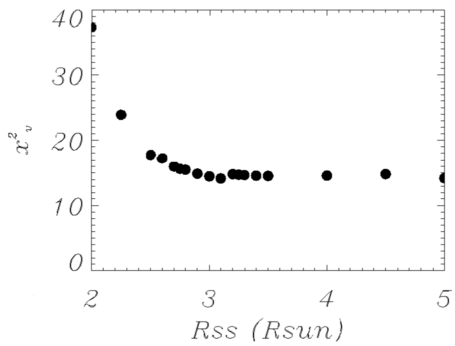


**Fig. 4.** Value of $\chi^2$ (see text) as a function of PFSS source surface radius ($R_{ss}$)

lar activity of cycle 23, when the solar corona was relatively stable, with a quasi-dipole axis-symmetric global magnetic field configuration (e.g., Mancuso & Spangler 2000). In a future work we plan to perform this kind of study on different phases of solar cycle, although, we expect that a more tangled identification of the neutral line, since at solar maximum the magnetic field configuration is more complex and rapidly changing. During the period of interest, corresponding to the solar minimum phase of the solar cycle, UVCS performed a almost daily synoptic observation program covering the full corona at heliocentric distances 1.5, 1.7, 1.9, 2.2, 2.6, and 3.0 $R_\odot$ at 8 different roll angles separated by 45°. Moreover, complementary *special* observations have also been included in our study whenever the pointing was the same as the synoptic program. We combine the spectral data in order to obtain a temporal resolution of about one day. Then we determine the total spectral line intensity from calibrated and combined UVCS data, by fitting the spectra with a function resulting from the convolution of a gaussian function (for the coronal spectral profile), with a Voigt curve describing the instrumental broadening, and a function accounting for the width of the slit

(Giordano 1998). For the equatorial observed roll angles, East (90°) and West (270°) limb, we built synoptic maps of the H I Ly$\alpha$ intensities covering about 55° in latitude. For a detailed description of the procedure to reconstruct the UVCS synoptic maps at a given slit position from spectral data, see Giordano and Mancuso (2008). These data sets have been used to obtain Carrington maps for each limb at the different heliocentric distances corresponding to the 6 slit positions that may be thought as sections of coaxial cylindrical surfaces (see Figure 2). The obtained H I Ly$\alpha$ synoptic map (see Figure 1) represent the intensities interpolated over a section of the spherical surface at 2.5 $R_\odot$ in order to be directly comparable to the theoretical neutral line as calculated with the PFSS model. As in Guhathakurta et al. (1996) work, we derived the position of the heliospheric neutral line assuming that it corresponds to the maximum of the observed H I Ly$\alpha$ intensity (along latitude) at each heliographic longitude. Comparison of the PFSS model with UVCS observations is shown in Figure 3.

## 4. Preliminary results

Although the theoretical and observed neutral lines are seen to be in good agreement (Figure 3), we verified how a different position (other than the canonical 2.5 $R_\odot$) of the source surface could affect our result. We thus shifted the source surface position over a range of heights from 2.0 up to 5.0 $R_\odot$ and compared again the results so obtained with the one derived from the above described UVCS observations using a $\chi^2$ goodness-of-fit approach (see Table 1 and Figure 4). The result hints to the fact that the source surface in PFSS models should be actually positioned higher than the two canonical 2.5 $R_\odot$ and possibly lower than about 3.25 $R_\odot$. It is our intention to verify these preliminary results by extending our analysis to other sets of prominent lines observed by UVCS during the synoptic program, such as the O VI 103.2 and 103.8 nm and the Si XII 49.9 nm and 51.2 nm spectral line doublet.

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