# CONTRIBUTON TO MODELING OF CORONAL MAGNETIC FIELD

**Marcel Bělík[1], Pavel Ambrož[2], Eva Marková[1]**

[1]*Observatory Úpice, 542 32 Úpice, Czech Republic, Email: belik@obsupice.cz, markova@obsupice.cz*
[2] *Astronomical Institute Acad. Sci. Czech Rep., 25165 Ondřejov, Czech Republic, Email: pambroz@asu.cas.cz*

**ABSTRACT/RESUME**

The source surface radius presents one of the boundary condition in the solar coronal magnetic field modeling. They affect the shape of the computed magnetic structures. The total solar eclipse pictures of corona, processed by numerical method, show very faint structures, extended from chromosphere to the several solar radii. These structures represent the possibility of visualization of real magnetic situation in corona. The analyzing of shape of these coronal structures helps us to determine as exact as possible value of source surface radius. We discuss some problems of calculation of its value and the evolution of source surface radius during solar activity cycle.

## 1. INTRODUCTION

It is generally accepted that the coronal structures are dominantly formed by magnetic fields in solar corona. Therefore, the knowledge of coronal magnetic situation can help us to understood observed variety of shapes and structures. Unfortunately, the direct measurement of this coronal magnetic field is practically very difficult at present time. Only indirect methods and mathematical models can be used to describe the magnetic situation. The total solar eclipses bring very good possibilities to visualize coronal structures, and subsequently the coronal magnetic field, from the solar surface to the distances of several solar radii. Comparison of observed and computed magnetic structures can help us to choose the efficient boundary conditions for the mathematical models.

## 2. SOURCE SURFACE RADIUS DEVELOPMENT DURING SOLAR CYCLE

Very good conditions during total solar eclipse on June, 21th, 2001 in Angola (Marková et al, 2001) and new mathematical methods of image processing (Bělík et al., 2003) allows to obtain the pictures of very faint coronal structures, which should visualize coronal magnetic fields from the solar surface to the several solar radii.
We can identify both radial and diagonal structures in these pictures. The spatial resolution of faintest coronal structures in the coronal loops is about 6000 km.
The inclination of all observed coronal structures from the radial direction were measured on eclipse picture with the aim to find effective distance above the solar limb, where only radial structures are presented. Result presented in Figure 1 shows, that usually used value of solar surface radius $R_{ss}$ = 2.5 $R_s$ is not acceptable for this eclipse. We can see that at this distance the diagonal structures are still dominant and the radial direction of them could be found at 3.2 $R_s$ minimally. The condition of radiality is even probable achieved at 4.5 $R_s$.

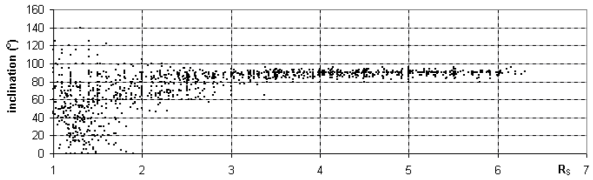


Figure 1. Inclination of coronal structures from the radial direction (Angola, 2001 eclipse)

We analyzed the pictures from 8 total solar eclipses during the 1990-2001 period. We found the different values of the approximate source surface radius during solar cycle. This development is shown in Figure 2. Another dependence in this figure represents the temporal development of the Ludendorf ellipticity values, derived from equal eclipses (Marková and Bělík, 2001). Both curves shows reverse course during the 1990-2001 period.

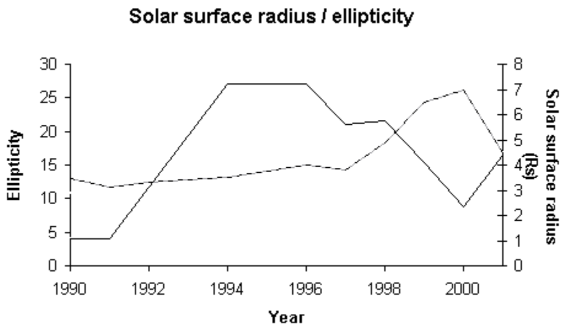


Figure 2. Development of $R_{ss}$ (dashed line) and ellipticity (bold line) during the period 1990-2001.

## 3. MAGNETIC FIELD MODEL

Determination of the magnetic field structure in the coronal space is still impossible from direct measurements. Since pioneer work of Altschuler and Newkirk (1969) few different approaches were used for extrapolation of the photospheric fields. In our calculations we used model modified by Zhao and

Hoeksema (1993, 1994) and usually cold as the Horizontal Current sheet-Source Surface (HCSS) model. Model is built on the magneto static equilibrium and the source surface technique. It contains two important free parameters that we tried to determine from observations of the fine structure of the corona. Whereas the radius of the source surface $R_{ss}$ represents the outer boundary of the spherical shell in which the extrapolation is realized, above this radius the magnetic field must have only radial component. Maximal radius on the coronal pictures, where only radial structures are observed can help us to determine this parameter.

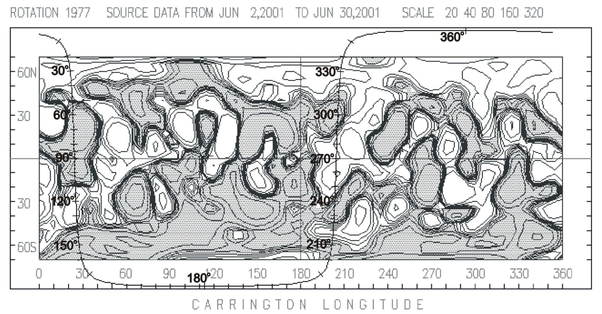


Figure 3. Synoptic chart of the photospheric magnetic field for CR1977 derived from WSO spherical harmonic coefficients with maximal principal number $n$=19. The continuous line represents position of the solar limb for moment of the total solar eclipse with coordinates of center of the solar disc $L_o$ =114.2$^o$ and $B_o$ = 1.8$^o$.

Extrapolation model uses the inner boundary condition the photospheric magnetic field reconstructed from spherical harmonic coefficients, available from WSO observations. Maximum used principal index is $n$=19. Simplified solution of the magneto static equilibrium can be obtained if an electric current in photosphere is assumed to flow perpendicular to gravity. Including of such horizontal volume current into our model as parameter $a$ we have possibility to manipulate with shape of the magnetic field lines above the photosphere. When $a$>0 the appropriate magnetic force acts to expand field lines upwards.

The calculated magnetic field remains current-free and makes possible to compare expanded structures with coronal observations or shows the general character of the coronal magnetic field.

## 4. IDENTIFICATION OF CORONAL STRUCTURES

Identification of the magnetic structures we try to demonstrate above many separate limited regions near the line representing the solar limb as drawn in Figure 3. The contribution to magnetic structures is from different regions on the magnetic synoptic chart in solar polar regions mainly.

Results of many extrapolation attempts are documented in Figure 4a-f. For each calculation, producing field lines in position angle interval P[low, high] we specified the region on the synoptic chart S[longitude-minimal, longitude-maximal] [latitude-maximal, latitude-minimal]. For each calculation the radius of the spherical source surface was used $R_{ss}$ = 4.5 $R_s$ and the parameter characterizing horizontal current density H[from 2 to 3] is labeled for each calculation in Fig. 4.

In background of each picture is identical photo of the solar corona. Within solar limb are labeled by letters typical structures observed in corona (arcades by ***a***, gaps in coronal brightness by ***g***, loops by ***l***, helmets by ***h*** and streamers by ***s***).

Structures of field lines in Figures 4a and 4b are extrapolated from bipolar regions on both sides of the equator, where magnetic flux is dispersed into many individual islands. Principal orientation of the neutral line is in meridional direction. In the inner corona many loop like structures can be found, but their fine structure is not very clear. Field lines coincide well with loop structures ***l1*** and ***l2***. Streamer ***s1*** is created by great loop with plane oriented parallel to the line of sight. Similar projection of one loop into nearly radial streamer is also in the case ***s4***. Arcades ***a2*** and ***a5*** are coincides very well with neutral lines crossing limb at latitudes S37 and N43 respectively. Gaps ***g2***, ***g3*** and ***g4***, coincides well with open field configurations, originated between two neighboring closed arch systems in one region of the equal polarity. Gaps are characterized by low radiation. Model is not able to demonstrate boundaries of the helmet structures in the medium and outer corona on position angle from 50$^o$ to 105$^o$. System of arcades ***a1*** in the inner corona in Fig. 4c are connected with field lines from complicated structure of the neutral line near limb line at latitude N40-N50.

High loops extending to the outer corona can’t be found on the corona photography and the model is so far from solar photosphere not valid. Similar situation is on the west limb in Fig. 4e, where arcades ***a5*** (not very distinct in corona) are perfectly modeled by field lines. Inclined helmet system ***h2*** also coincides very well. Very great loops follow the streamer structures ***s4*** only in the inner corona, but substantial disagreement we see in outer corona. Many nearly radial polar streamers modeled in Fig. 4e coincide well with open field lines, calculated by model.

Arches and streamers on the southern hemisphere are modeled on figures 4d and 4f, where field lines for ***a2***, ***a3*** and ***a4*** coincides very well with observation. Streamers ***s2*** and ***s3*** found not support in our extrapolation. Streamer ***s3*** is strictly radial and therefore it is very probably upper part of helmet structure, rooted into photosphere on the far side of the sun, probably in region with S [140,165], [35,15] which is minimally 50$^o$ behind the limb.

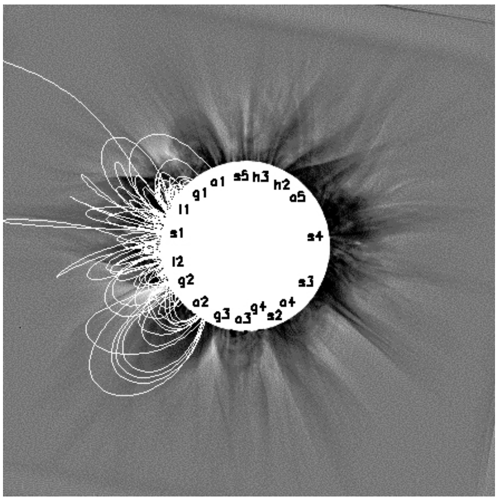

Figure 4a. P[40,120],S[5,55][40,-30],H[3]

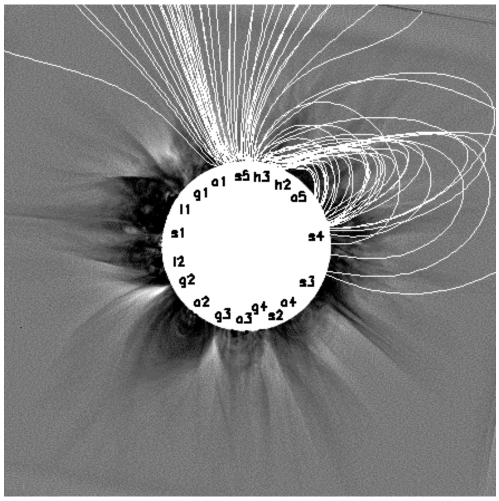

Figure 4e. P[275,10],S[210,360][88,70],H[2]

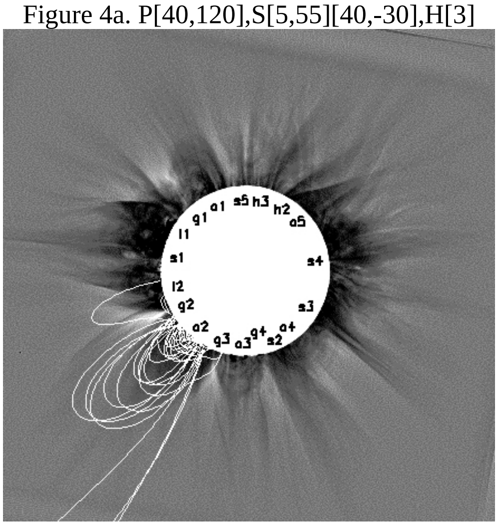

Figure 4d. P[115,165],S[0,35][-30,-62],H[3]

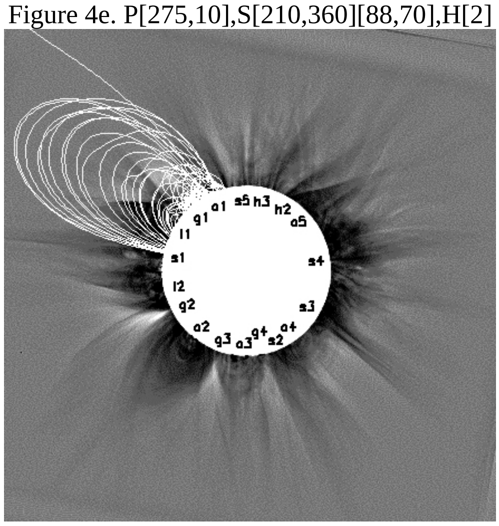

Figure 4c. P[15,80],S[5,80][40,70],H[3]

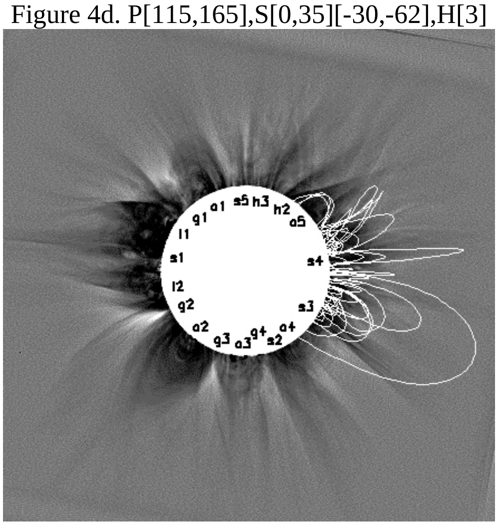

Figure 4b. P[225,330],S[180,210][30,-25],H[3]

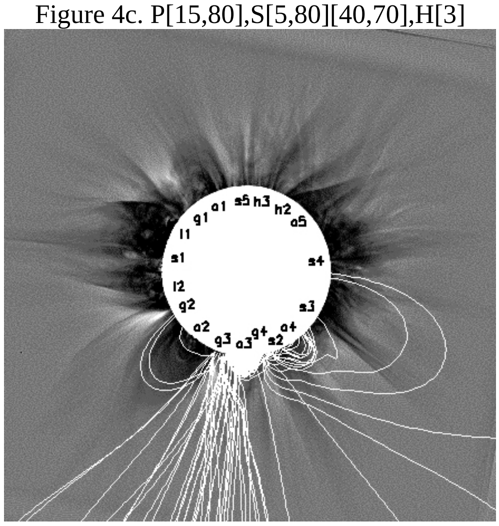

Figure 4f. P[120,220],S[10,220][-65,-85],H[3]

Figure 4. Set of pictures representing superposition of the extrapolated field lines (white lines) into identical structures of the white light corona. Below each picture is presented position angle interval with calculation of field lines on the limb P[low, high], region where starts the field lines from photosphere limited by heliographic coordinates S[longitude-minimal, longitude-maximal][latitude-maximal, latitude-minimal] and the parameter characterizing horizontal current density H[from 2 to 3].

## 5. CONCLUSION

Modern numerical methods of the image elaboration are able to provide us the much detail filtration of the smooth large-scale variations of the brightness and make possible to enhance the small scale structures like narrow coronal streamers, boundaries of the helmet structures and fine structure of arcades and coronal loops.

Methods usually used for enhancing of the fine structures of observed white light coronal pictures aims to remove signal of a large-scale background with low spatial frequency, whereas the fine structures with medium and high spatial frequencies are enhanced. Resulting coronal image after this filtration shows many loops and arcades, helmets and streamers. Their total local brightness however is not comparable between different points of the coronal picture because the background information is missing. Obtained structures show superposition of many different coronal structures projected together into one observing plane, many times from magnetic structures being displaced apart and not having organic relationship. Local brightness on processed images then does not relate with radiation from separate structures because large-scale component was removed.

Identification of the magnetic structures we demonstrated on many separate limited regions near the line representing the solar limb.

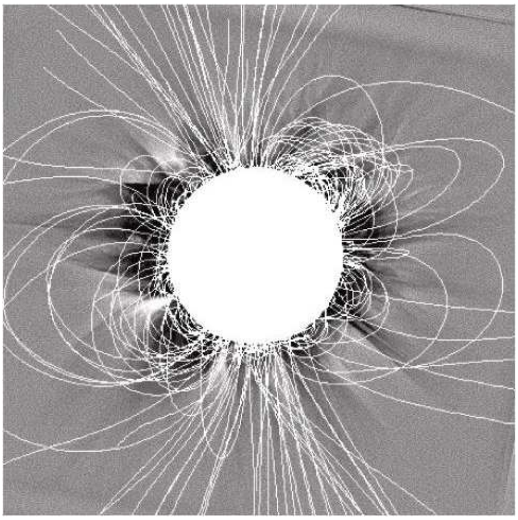

Figure 5. Extrapolated structure of the magnetic field in corona, computed according to HCSS model for total solar eclipse in June 21, 2001. The source surface radius is 4.5 $R_o$ and parameter of horizontal current is $a$=3 Maximum principal index is $n$=19. Coronal structure coincides with model mainly in low and middle corona. Many field lines are not in observable relationship with coronal plasma.

The contributions to magnetic structures come from different regions on the magnetic synoptic chart especially in solar polar regions. Nearly all low corona loops and arcades as well as some streams and helmet structures were identified on both coronal and magnetic field line pictures. In equatorial zone ± 50$^o$ all low corona structures are connected with magnetic regions in near limb sector with longitude interval up to ± 25$^o$. Streamers in the outer corona can be rooted in photosphere in regions distant from solar limb up to 60$^o$.


## ACKNOWLEDGMENTS

*The Wilcox Solar Observatory magnetic data used in the present study were obtained via the web site http://quake.stanford.edu/~wso. The WSO is supported by NASA, NSF and ONR. The present work was carried out with the support of Grant of GA/AVČR No. A300030506. Authors are grateful to M. Druckmüller for kind processing of eclipse pictures.*


## 6. REFERENCES


Altschuler, M. D. and Newkirk, G.: 1969, *Solar Phys.* **9**, 131.

Bělík, M., Druckmüller, M., Marková, E., Křivský, L.: 2003, *ESA SP-535*, 741.

Ludendorf, M.: 1928, *Sitz. Ber. Preuss. Akad. Berlin, 16*, 185.

Marková, E. and Bělík, M.: 2000, *Observations et Travaux*, no. 53, 19.

Marková, E., Kotrč, P., Křivský, L., Bělík, M., Dušek, J. and Urban, J.: *ESA SP-447*, 245-248.

Zhao, X. P. and Hoeksema, J. T.: 1993, *Solar Phys.* **143**, 41.

Zhao, X. P. and Hoeksema, J. T.: 1994, *Solar Phys.* **151**, 91.