# SEARCH FOR BASIC BUILDING BLOCK COMPOSING SOLAR ATMOSPHERIC STRUCTURES

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ABSTRACT

We present the data indicating for the existence of basic morphological building block composing the most of solar atmospheric structures. Presently, a growing number of high resolution solar observations (form radio to X-ray range) give evidence in favour of hierarchical organisation of the constituting structures. We introduce a geometrical model of the basic building block based on the available observations. Provided the concept of hierarchical organisation is applicable to solar atmospheric structures, the geometry of the basic element would have profound consequences in terms of influencing the transport equations in the solar plasma.

Key words: solar physics; magnetic fields; corona

## 1. INTRODUCTION

The morphology of observed solar structures is extremely complicated as observed in every spectral range. With increasing resolution of present instruments (both groud-based and space-born), the complexity of structures is observed to grow in proportion. From the other side, the models used in order to interpret properties of the observed structures are usually (in contrast) very simple (sinlgle coronal loop, arcade of loops or plane parallel atmosphere). Magnetic fields are assumed to be responsible for bottling the plasma in particular structure above the "transition region" while the gravity is assumed to force stratification of the atmosphere below. It is generally assumed that plasma transport is highly non-isotropic. In the corona, the transport is very efficient along field lines and prohibited across (low $\beta$).

In the present study we pop up selected images of solar structures where the pattern of the brightness (contrast) provide evidence for much more complicated organisation of links in the corona. These presented and the other observations reveal that the overall complexity of the structures seen in the solar corona may be broken up into elementary structures called: *building blocks*. These elements are supposed to be replicated in a self-organised manner over several orders of dimensions. The tiniest of them are seen at the present observational limit of ~hundreds of kilometers and are belived to be present on scales down to few kilometers on the Sun. The uper limiting dimension is the size of the overall corona (cf. coronal helmets).

Below, we introduce and discuss a qualitative model of coronal magnetic field line organisation and give some physical reasoning standing behind it. We would like to note explicitly, that the model presented represents the **obvservers cartoon** and the physical reasoning standing behind, is at the same level.

Provided that suggested pattern of organisation reflects the actual system making the solar atmosphere and channeling the plasma particle transport processes, commonly accepted scenarios of solar atmospheric modelling have to be entirely reconsidered.

In the future, we will concentrate on finding further observational and theoretical arguments in support of the presented concept.

## 2. THE OBSERVATIONS

The inspiration for the present research came from inspection and analysis of various solar observations. Especially important in this respect were the images of protuberances, SXT pictures of flaring and active regions, TRACE animations of the EUV bright structures and the high resolution images of the photosphere. The high resolution radio imaging supports also the concept presented. As concerns the SXT images, we have been inspired by looking to hundreds of deconvolved images. Deconvolution removes the instrumental blurring and increases the spacial resolution down to ~1 arcsec level (Sylwester and Sylwester, 1998, 1999c). In the following, we show a number of images, in which, to our opinion, the suggested picture of the coronal links is well distinguished. We selected to present observations showing structures seen above solar limb. In this way we attempted to avoid the ambiguity of projecton effects. Disc observations which are in support of the present model are presented in the parallel paper by Sylwester and Sylwester (1999b).

The emission patterns presented in Figs. 1-4 indicate, in our opinion, towards a peculiar self-organised character of coronal magnetic links. The appearence of structures allows to follow possible organisation

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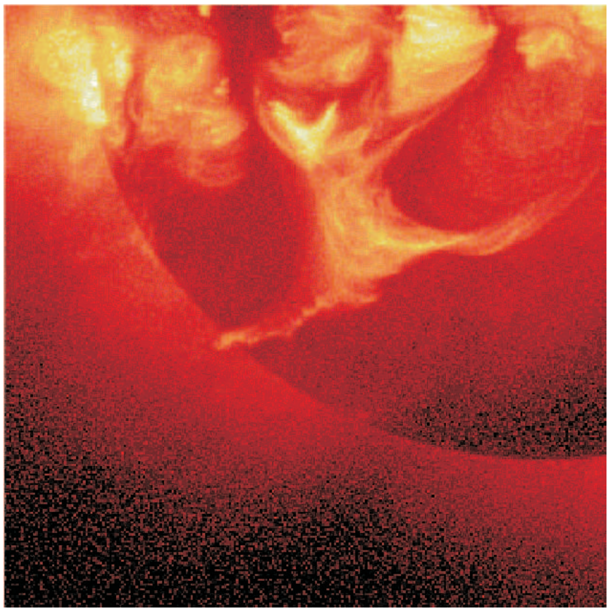

*Figure 1. The image shown was obtained from the Soft X-ray Telescope (SXT) on the Yohkoh solar research spacecraft on 26 February 1992. The image was taken at 20:01 UT. A well developed arcade structure is seen in eruption. The subordinate structure is seen towards the North-East direction. This picture has been taken from* `http:// mssly1.mssl.ucl.ac.uk/ ydac/ images/ scorpion_filament_eruptions.gif.`

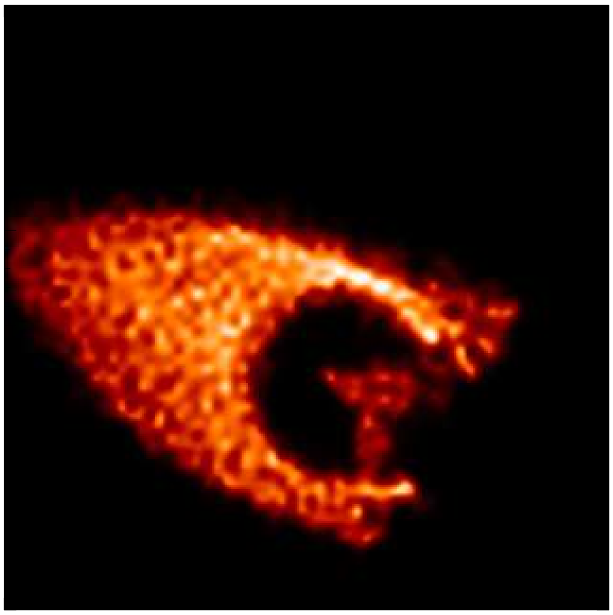

*Figure 2. Deconvolved Be119 SXT image of the flaring structure seen at the East limb on 21 February 1992 (Tsuneta et al. 1992). The arcade in projection along the ridge is seen with the underlying "lower order" loop system evident at the footpoint area. A subordinate arcade system has evolved on the central axis and in front of the structure observed.*

of magnetic links in the corona - the pattern non-envisaged earlier. Important are long lasting emission kernels and joining weaker interconnections. Some of the interconnections (ridges) join the kerners directly. We infer that there must be magnetic field lines "originating" in kernels, providing transport links between them. Driven by the appearence of emissivity pattern of structures observed in the corona, we came to the concept of hierarchical structure of magnetic links. Based entirely on the observations, the following observational evidences are to be taken into account in any realistic concept of the coronal model.

- The EUV, soft, hard and white light (WL) emissions of flaring bright patches are very dynamic with the observed velocities of transversal "motion" of the bright emission kernels in the range between 20 - 100 km/s. Reorganisation of the links takes place on time scales of few seconds only. Observed bright structures resemble arcades of loops being activated by propagation of the exciter along them or/and from the above - i.e the higher rank structure.

- Presence of emission kernels persistent higher-up in the corona is evident. These kernels share their identity while moving in the corona. Translational motions tend to be related with appropriate Doppler line shifts (Sylwester and Sylwester, 1999a) which advocate for the real motions of the kernels. The structures connecting coronal kernels are numerous, often oriented paralel to the photosphere.

- The location of EUV, soft, hard and WL emissions do not generally coincide. In cases they do, the apparent coalignment can probably be assigned to projection effects. The HXT emission kernels are usually placed sideways relative to corresponding soft X-ray kernels.

Present high-resolution solar observations indicate that solar corona possess the fractal structure and is composed of elementary building blocks. It seems that in all the solar images, the pattern of bright (high contrast) connections resembles the scorpion with several "legs" joining towards the lower, smaller scale regions and few branches joining towards the upper higher-order structures (as shown schematically in Fig. 5b). In no one of the examples presented a simple model, or the combination of simple models can adequately describe the observed morphological complexity. The observations presented reveal, in our opinion, a characteristic pattern of connections which tends to be present in all the stuctures observed on the Sun. According to our opinion, the basic building block of solar coronal structure consists of a system of driving and induced current systems (cf. Fig. 5) being represented as magnetic field lines. These are field lines where the most of coronal plasma is concentrated, giving rise to the enhanced emission/absorption in various portions of the solar electromagnetic radiation.

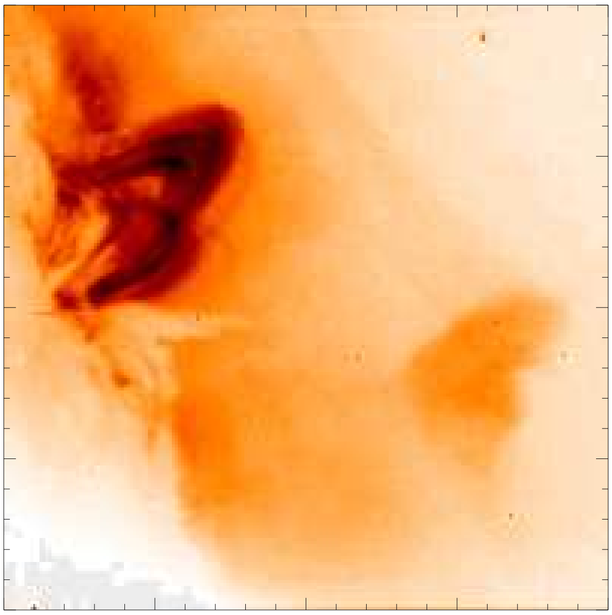

*Figure 3. The 171 ÅTRACE image of active region observed on west limb on 6th July 1998 ~12:30 UT. Please note the cusp structure hanging in the corona much above the limb (lower right section). The curvature of the limb can be noticed.*

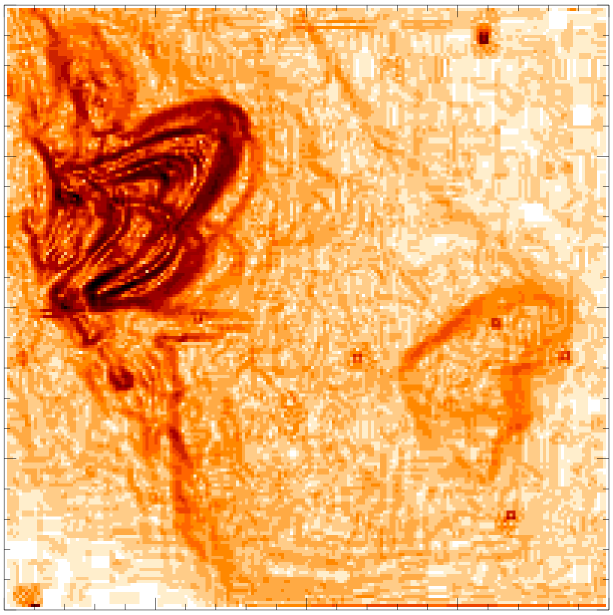

*Figure 4. The same area as in Fig. 3. We enhanced the contrast using the* **sobel** *IDL operator. Many fragile interconnecting structures can be easily identified. Note the structure in the lower-left section. It is easy to see field lines originating in the many kernels located up in the corona. No possibility is left that the field lines are rooted in the magnetic elements in the photosphere for the observations presented. Therefore no extrapolations of the photosperic field lines may accomodate for the structures observed. This single observation contradicts the classical scenario that all field lines present in the corona are direcly rooted to corresponding magnetic elements at the solar surface. The full evidence is to be observed in the animations available at our* `http://www.cbk.pan.wroc.pl/publications/1999/basic.htm` *site.*

## 3. THE HIERARCHY CONCEPT

From the many detailed observations of the solar structures, we arrived to the concept of hierarchical type of organisation for the structures seen in the solar atmosphere. This hierarchical concept brings necesserily the idea of fractals and the "basic topological structure" forming, in the repetitive way, the overall magnetic configuration of the corona. We propose the following scenario: the corona consists of numerous interlinked basic structures: "scorpions". Within the body of the "scorpion" the transport processes are operating along the branches. Some of the branches are going downward, some upward and many horizontal. In Fig 5 we present the geometrical model standing behind the proposed scenario.

Most of the evidences in favour for the present model come from observations of flaring patterns. However, the basic scorpion structure is the most easily recognized during non-flaring periods. We have noticed that during the phase preceding the formation of the scorpion, the submergerged magnetic field lines evanece (Fig. 5a). This action driven from below forces the coronal plasma to counter-react. Induced currents are created opposing the intrusion. The currents are flowing wherever possible i.e. where the circuit can be closed. Regions of flowing currents can be identified possibly from radio/hard X-ray emission (HXE) observations. The induced current systems aim to counter-react the forced change from below and develope respective closed field lines not directly linked to the photospheric magnetic elements.

The essence of the concept is that the closed field lines are formed in the corona driven by emerging flux ropes. These field lines are initially separated from these evanescing structures.

This concept is illustrated in Fig. 5b. Some of the "induced" field lines tend to find their identity by passing below the evanescing arcade of field lines. The early formation of the "counteracting" pattern of coronal currents seems to be a basic response of the corona against the perturbing penetration.

The uneasy question to answer is: why and how do the intermixed current systems communicate to each other in order to simplify the build-up of the stresses. We suggest the following description.

As the induced current system evolves, corresponding magnetic field lines are coming into proximity with the underlying structures. Provided that some of the induced field lines do reconnect with the underlying structures within the primary reconnection kernels, the channels are opened to feed the coronal structures with the plasma. Inside the kernels, the field simplification takes place with the appropriate energy release. As illustrated in Fig. 5c there are two regions (primary kernels) where the magnetic tensions are the strongest. In between a quiet reconfiguration of magnetic stresses may take place. These secondary kernels may contribute in feeding the EUV

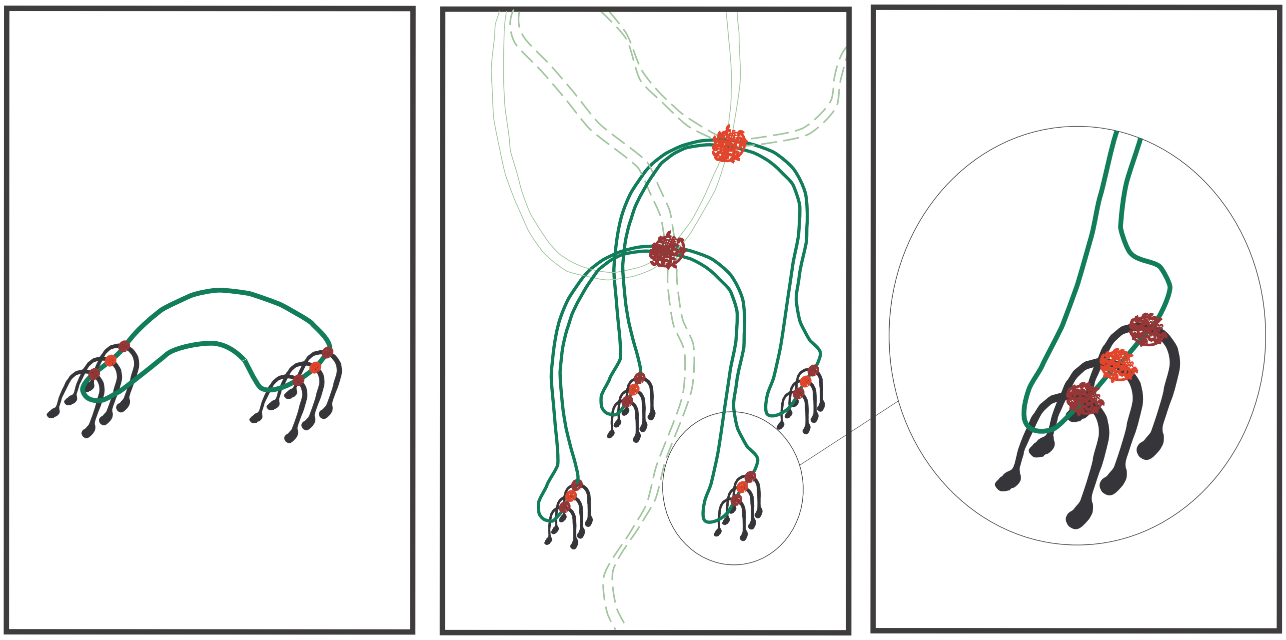

*Figure 5. Illustration of the basic concept of magnetic field organisation in the corona.See the text for details.*

post-flare loop or protuberances.

Within the basic scorpion structure, the field relaxation causes corresponding energy release in many places. As envisaged by Jakimiec at al., (1998) the magnetic stresses present within the primary interacting regions may lead to development of strong local MHD turbulence. As the field lines are supposed to be intermixed within the primary (and secondary) turbulent reconnection regions, some of the energy released is transported down, some up, and some in between the primary/secondary reconnection regions i.e. along the "ridge". Downflow of energy released from the primary regions formed just above the photosphere can be only counter-reacted by appropriate mass (enthalphy) upflow (as many hydrodynamic simulations predict). These flow feeds the primary kernels with the plasma. Following the turbulent MHD processing, part of this plasma can be further transported upwards along the upgoing field-lines, and part towards the secondary kernels. A substantial part will be returned back to the photospere from the secondary kernels as explained below. As the energy release witin the secondary kernels is supposed to be less efficient as compared to the primary one, the plasma radiative losses may dominate there. As a consequence the plasma may cool fast and drain along the down-leading magnetic branches. Provided the stresses in the system build up slow enough, the evolution may be calm and quasi-stationary. However, a single reconnection within any of the kernels may brake the entire topolgy of the system, causing violent reorganisation of the magnetic links in the corona (flares). This type of connection breaking is expected to originate from interactions with the solar wind.

Within the proposed model, the entire solar corona is build up of basic building blocs - "scorpions" of various dimensions interlinked into a hierarchical structure. It is envisaged that some of the induced field lines are formed below the forcing field. The system (entire corona) is supposed to have enough freedom to offer the links (for the induced current) on the trans-equatorial scale. There seems to be, however, selection rules present mitigating the allowed connection pattern. One of the supposed field-connectivity selection rules may be related with the helicity of the evanescing structures. Provided that local (within the evanescing magnetic structure) links are the only allowed, a simple bright point structures are expected to develope and the hierarchical "order of complexity" is low (first - second order).

The complexity of links becomes higher within active regions. As mentioned, the higher order links are expected to establish connections between active regions present on the opposite solar hemispheres. The study of development of these trans-equatorial links may probably offer a direct test of the present concept. Presence of these links constitutes a hard problem for the "classical models".

The highest order scorpions are expected to be directly linked to the interplanetary (yet higher to interstellar) solar wind field lines. The tension of the links imbedded into outflowing solar wind may cause the higher ordrer scorpions to be accelerated out of the Sun (CME's), provided that the counterpart downlinks have been weakened or broken (flares).

Within the present scenario, the two magnetized plasma media creating the stressed hierarchical structure of the active solar atmosphere are:

- the constantly evanescing from below the solar surface magnetic elements (bipoles). They constitute a driver and feeds the energy
- the openning of magnetic links (from inside of the

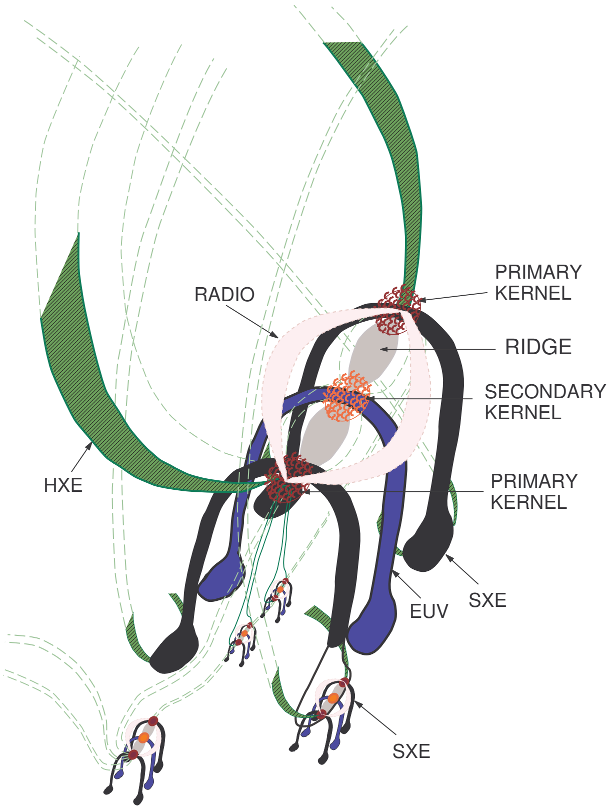


*Figure 6. Scheme of structures observed in the lower corona contributing to the various observed emissions. The most important are the kernels (primary and secondary) where the turbulent reconnection of field lines takes place. Most of the field lines present in the corona originate in such kernels. For the fuller description see the text.*

magnetic structure) to the solar wind constitute the main relaxation process.

It is supposed that the radiation being emitted within the hierarchical structure plus the other terms constituting the energy balance equation (CME kinetic energy for instance) are contributing to the observed emissivity variations. The energy release processes are expected to take place predominantly within the primary energy release kernels within each of the many scorpion structures present at any time. In Fig. 6 we present a detailed scheme of the magnetic links in between many scorpions. Due to the postulated self-critical state of the system, the energy release is expected to be catastrophic, with many small scale energy releases (microflares) and rare large energy releases involving substantial part of the stressed system relaxation (flares). Constant dynamic reorganisation (simplification) of links between kernels is envisaged. Most of the emerging magnetic field lines (flux) cancel back provided that selection rules for the cancelling are satisfied. A small portion of the unmatched magnetic flux opens up however into the solar wind through a cascade of reconnections within consecutive kernels.

The kernels' dynamics is a subject to a transient balance of the forces acting upon it. Among the important are: the gravitational forces and the magnetic forces due to tension of field lines entering the kernel. Motions of the kernels are predicted if these forces are not balanced. In case of kernels moving towards each other with the connecting field lines present, particle acceleration is envisaged. Magnetic mirroring can be involved between the kernels, provided field lines have appropriate geometry. Rebouncing of particles may happen from the turbulent surface of the kernels causing gain of energy for the reflected particles. Adiabatic compression of the plasma can play a role in heating of the plasma confined in the trap between colliding kernels.

Within the model suggested it would be highly unprobable to have coronal field lines rooted directly to the photospheric magnetic elements. A standard would be the situation, where the accelerated particles precipitate into the dense kernel rather than into dense photospheric layers.

The temerature of the low order kernels should be controlled by the contact with the photosphere. In case of the highest order kernels the links into solar wind are expected to be efficient in cooling.

The average density of kernels should follow the RTV scaling low relation (Rosner, Tucker and Vaiana, 1978) provided that quasi steady state conditions are reached (Serio, 1990). Reaching equilibrium might however take longer times, since the transport of plasma to the higher order kernels will not be direct (to reach given order, the plasma has to cross at least single tyrbulent kernel).

An interesting aspect of the model proposed is that any plasma entering the corona has to be preprocessed in the lowest order plasma kernels. In this MHD processing diffusion effects might be of importance contributing to differences in the abundance composition between the photospere and the corona. It might be easy to understand provided that the lowest primary kernels are processing the plasma with temperature ' $T \sim 10^4$ K. FIP effects might be important within these regions.

The first order kernels are expected to be located only few hundred km above the photosphere and are supposed to be the structures where the spicules are rooted.

## 4. CONCLUSIONS AND MODEL PREDICTIONS

Within the suggested scenario, there are numerous follow-on predictions. Here we list some of the important.

- The nature of energy release in active coronal structures is of self-organised charater (i.e. avalanches are expected). In respect with the amount of energy release it is very much unpredictable (like in earthquakes). A brake of a single magnetic link may result in a global catastrophe and the release of substantial free energy contained in stressed current system.

- It is envisaged that permanent turbulent reconnection is taking place in the corona within many of the primary reconnection kernels. As a result appropriate spectroscopic evidences are to be sought.

- As the kernels move due to inbalance of the forces acting on them, directed plasma motions should be seen for flare events observed at the limb. Multiple Doppler components may be present in the spectra, related to the individual kernel's emission.

- The draining of plasma from the seconary kernels is expected. These plasma motions may contribute to the overall redshift observed in the most of EUV lines.

- The power low spectra of many active solar phenomena come as the natural consequence of the self-similar pattern of the magnetic field organisation.

## ACKNOWLEDGMENTS

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