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CONNECTIVITY PATTERN IN THE CORONA

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Abstract. We present images of the structures indicating for the existence of hierarchical, self-similar organization of global connections in the solar atmosphere. We discuss a geometrical model of the basic building block, the atmosphere is envisaged to be made of. The important elements of the proposed building block are the plasma kernels and the connections between them. It appears that the concept of hierarchical organization is generally applicable to solar atmosphere from the base of the photosphere towards the interplanetary space. If so, we point out profound consequences of such hierarchical system for transport of energy and dynamics within the solar atmosphere. Possible scenarios for the plasma dynamics and acceleration mechanisms are also outlined.

Key words: solar plasma - magnetic fields - atmospheric structures

1. Introduction

Over past decades, space as well as ground observations of the Sun have revealed many interesting emission features. Practically all of them show emission structures which are (most probably) tracing magnetic field lines. Such observations in conjunction with good magnetograms (MDI) more or less enabled to figure out general idea of the coronal magnetic fields as a direct extension of flux-tubes evanescing (through funnels, McKenzie et. al, 1998) from below the photosphere in the form of magnetic elements. This "classical" view is summarized in Figure 1. The morphology of solar structures is extremely complicated as observed in every spectral range. With increasing resolution of present instruments, the complexity of structures is observed to be

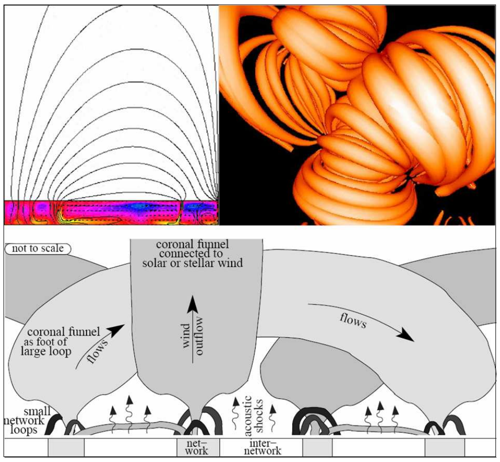


Figure 1: **Upper-left**: Snapshot from the movie (`http://soi.stanford.edu/press/ssu11-01/TRACE /mhd361n300_3.mov`) showing the evolution of magnetic field lines as obtained form MHD modelling of the interaction of the corona with the sub-photospheric convecting layers (Hurlburt and Rucklidge, 2000). Relevant talk of Uitenbroek containing basics of MHD formulations can be found at the address: `http://science.nasa.gov/ssl/pad/solar/presentations/UitenbroekTalk.pdf`. **Upper-right**: Nested system of simple loops placed in three dimensions representing "coronal extension" of the magnetic flux tubes evanescent from below the photosphere. For interactive animation visit: `http://science.nasa.gov/ssl/pad/solar/CurveHome.html`. **Bottom:** Sketch of the transition layer between the photosphere and the low corona illustrating the funnels (Peter, 2004).

getting even more perplexing. From the other side, the models used in order to interpret properties of the observed structures are usually pertinently referring to "single loop" or arcade of individual loops. More elaborated "three-dimensional" modelling makes often use also of the concept of a simple magnetic flux-tube, being replicated on various scales and tightly packed inside a coronal active region (Aschwanden et. al., 1999). In the most advanced MHD models, the concepts of fans, spines and separatrix surfaces bring sufficient necessary complexity into the description, making the comparison with the observation easier but more ambiguous (Priest, 2001). However, in the most of the solar atmosphere the magnetic fields are believed to be responsible for passive bottling the plasma in particular magnetic structure with the gravity playing role on the longer sizes/time scales. It is gener-

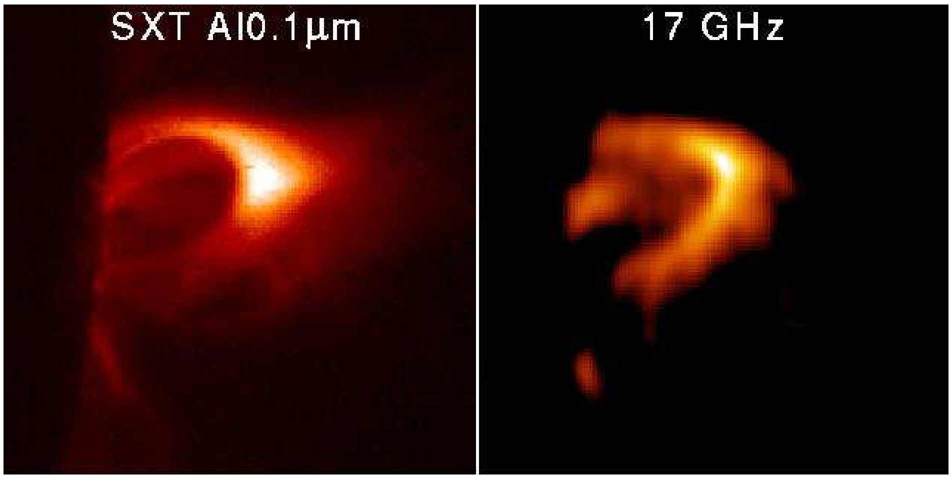


Figure 2: Images of thermal emission ($T \sim 1$ MK) from 16 March 1993 limb flare. The left panel shows the soft X-ray image taken by *Yohkoh* satellite, and the right panel shows the NoRH 17 GHz image. The loop-like structure is almost common. But detailed study indicates the intensity distributions are a little different in these images. A particularly interesting is presence of small curly structure at the place where the longer loop origins. Figure from `http://solar.nro.nao.ac.jp/norh/html/gallery/sun_1mk.html` and the references therein.

ally assumed that plasma transport is highly non-isotropic, being very efficient along the field lines (this processes being rapid, because information is transmitted along the flux tubes at the Alfven speed) and (in comparison) nearly completely prohibited across. The condition of plasma being frozen-into the field is expected to be valid about everywhere in the visible portion of the atmosphere, with the importance of the magnetic forcing growing in regions of lower plasma β (β – gas-to-magnetic pressure). Flux freezing in the coronal plasma is relaxed when local field gradients become sufficiently steep: the magnetic field then changes its topology, and releases energy by reconnection events. Transition from the dominance of gas pressure ($\beta > 1$) to magnetic field pressure ($\beta < 1$) occurs within the observed layers (transition region). In a picture shared at present by the most of researches, so called magnetic funnels are rooted in the network elementary magnetic flux-tubes. They are rapidly widening to fill the whole space in the corona. In order to understand the emissivity observed in lines formed below 10^5 K, Dowdy et al. (1986) and Peter (2002) postulate presence of closed loop-like structures below these magnetically open funnels (cf. Figure 1). Without the magnetic field, the temperature of the atmosphere would become more or less horizontally uniform within minutes. With the inhomogeneous magnetic field present, its

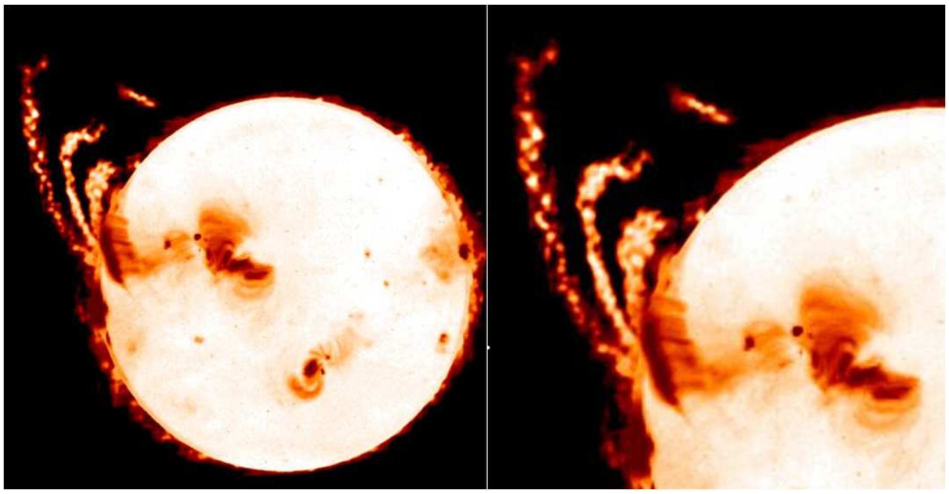


Figure 3: NoRH observation of the prominence filled with the plasma of relatively low temperature ($T \sim 10\,000$ K) taken on 31 July 1992. This is a composite image: The three "filaments" out of the limb are the snapshots at different times of a single erupting prominence. The disk image is a negative soft X-ray image, showing the arcade flare. On the enlarged portion of the image (right panel) the internal structure (multiple kernels) of the eruptive filaments are clearly resolved. Figure taken from `http://solar.nro.nao.ac.jp/norh/html/gallery/sun_10kk.htm`

concentrations would diffuse across plasma in time scale comparable to the age of the Sun only. This picture usually standing behind "classical" thinking of basic atmospheric structuring, certainly does not constitute a generally valid description for most (any?) of the phenomena observed in the solar atmosphere. In numerous cases rather fast (even timescales of activity cycle are fast for typical magnetic diffusion times) reconfiguration (as deduced from the observed changes of the morphology) is observed. This necessitates corresponding changes of the (directly invisible) pattern of currents contributing to the magnetic field. Some of the field lines of such time-varying magnetic configurations are distinctive by their brightness reflecting enhanced plasma densities. An outstanding problem is our lack of understanding about how the Sun chooses different field lines to populate with plasma - a kind of evaporation scenario might be in work - see the discussion later on. In the present study we pop up selected images of solar structures where the emission patterns particularly well indicate for specific organization of links in the corona. These patterns, however complicated by themselves, reveal to us some internal order, in the sense that the overall complexity of the structures may be broken up into segments similar in shape, but different in size. These elementary structures – *building blocks* – appear to be replicated and linked in a self-organized manner over few orders of sizes. These we call stages. The tiniest of them are seen at the present observational limit of ∼tens of kilometers in the photosphere. The largest observed structures: stramers and CMEs extend well into the interplanetary space filled with the solar wind, for many solar radii outwards.

2. The Images

Present research emerged as a result of inspection and analysis of many various solar observations, we have been looking to over tens of years. Especially important in this respect are 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, observations from the *SOHO* instruments like EIT, LASCO and MDI and recently, the high-resolution (< 100 km) observations of the photospheric structures from SVST. The high resolution radio images (Nobeyama Radioheliograph – NoRH) were of substantial importance (see Figures 2 and 3). The amount of observations we looked was very large. Here we will show examples only, those where the layout of structures seen is in a direct support of our idea of hierarchical structuring. However, even in these observations, the structuring of the atmosphere is very much obscured by the projection effects, limited resolution of the instruments or physical properties of the plasma being observed. It is our "a posteriori" finding, that structures of a given scale often contain plasma of similar physical characteristics (temperature, density) letting them to be well seen using a particular type

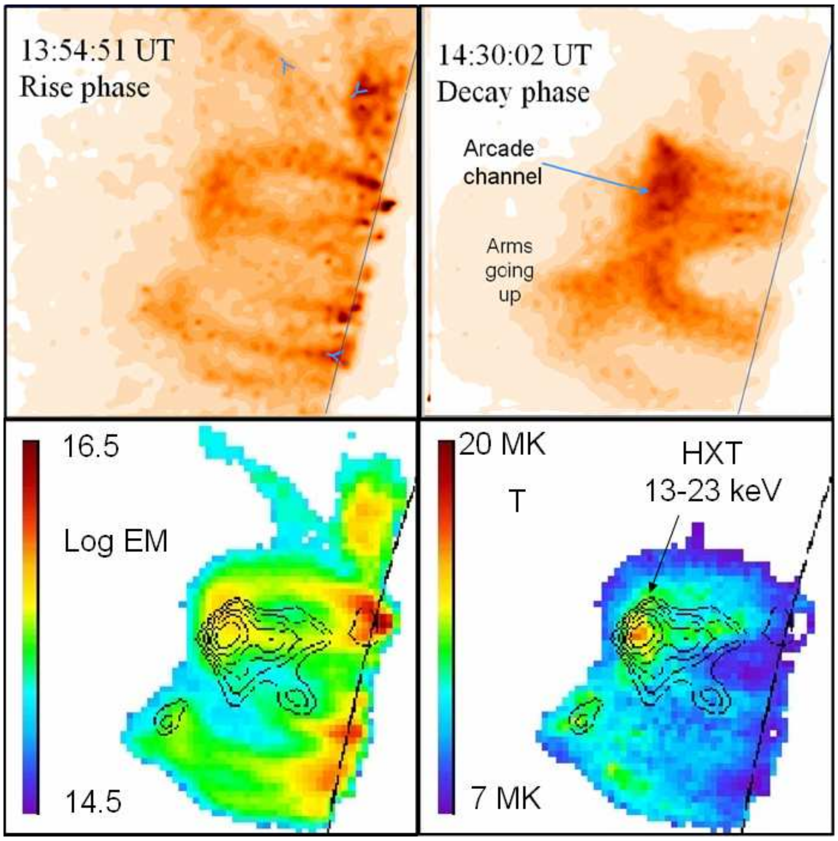


Figure 4: Limb flare of 28 June 1992, *Yohkoh* observations. See the text.

of observations (telescope) sensitive in a specific band only: X-ray, EUV, visible or radio. Structures of dissimilar sizes can be well seen all-together (in a given band) only rarely, in specific physical circumstances (slowly varying, cooling plasma).

In the example shown in Figure 3, multiple 17 GHz cool kernels are clearly distinguished in eruption. These multiple kernels could be the regions where arcade rays (spikey) origin. The supra-arcade flow field occurs between an assumed higher reconnection site (kernel) and the top of the loop arcade seen below in X-rays. This is as expected from the standard CSHKP (Carmichael-Sturrock-Hirayama-Kopp-Pneuman) model `http://solar.physics.montana.edu/magara/Research/Topics/cshkp.html`. 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 $\sim$1 arcsec level (Sylwester and Sylwester, 1998b, 1999a). In Figure 4, we show very instructive image of the "arcade" long duration (LDE) flaring system, in which, to our opinion, the suggested picture of the coronal links is particularly well distinguished. The system is seen close to the Eastern limb which is helpful to discern true widths and slightly avoid the ambiguity of projection effects. Observations of disc events which are in support of the present model are presented in the paper by Sylwester and Sylwester (1999). Study of LDE's are of spectial interest for morphological considerations, as the rate of changes in the configuration is slow enough for the variations to be seen with sufficient cadence. The flare shown in Figure 4, has been studied by Tomczak (1997) and is presented by Kosugi `http://soi.stanford.edu/results/ SolPhys200/Kosugi/images/21feb92/21feb92.html`. The evolutionary changes of the magnetic field configuration for 28 June 1992 are represented by X-ray emission observed using SXT aboard *Yohkoh*. The upper row images have been obtained using Be119 filter sensitive to emission of hotter plasma component ($T > 5$ MK) with the subsequent deconvolution applied. This removed the instrument point spread function, bringing-up details down to $\sim$1 arcmin. During the rise phase of this arcade (left image), within the "multi-loop" flare many "Y"-like joints are discernible (look for small "Y" signs). During the decay (right), the upwinded structures constituting the "extension" of the arcade spine are exceptionally well seen. In the bottom row the emission measure (left) and temperature maps derived using filter ratio technique for the rise phase are shown in respective shades. The hard X-ray (HXT) contours represent the hottest plasma component at ($T > 20$ MK). The flare shows many soft X-ray loop-like structures clearly. Some of them are "rooted" within the smaller "footpoint" bright loops, much shorter in size. In the HXT L-band images (13–23 keV), there are two hard X-ray sources near the loop-top of the arcade edge loops. This region corresponds to the high-temperature region in a temperature map. The hard X-ray patch is seen also at the edge of the footpoint loop. The pattern presented is typical of many events studied. One can easily imagine, that the arcade, similar to this presented in Figure 4 would resemble a single loop event with the X-ray source slightly above the soft X-ray loop apex, when seen edge-on. Studies and illustrations of such loop systems are overwhelmingly often meet in the literature, as they nicely fit to many of suggested flare scenarios - see cartoons collected by Hudson in "Grand Archive of Flare and CME Cartoons" `http://solarmuri.ssl.berkeley.edu/~hhudson/cartoons/`.

Another set of beautiful SXT images corresponds to two limb, multiple events evolving slowly on 29 November 1992 and 21 September 1999 (Figures 5 and 6 respectively). It is clearly seen, that the plasma kernels present at the "loop-tops" are the root-points of the other (presumed magnetic) connections. The kernels appear to play fundamental role in the organization of the structures seen. According to the concept proposed by Jakimiec et al., 1998, (see also Hugh Hudson atlas of flare cartoons `http://solarmuri.ssl.berkeley.edu/~hhudson/cartoons/thepages/Jakimiec.html`) these kernels (in the corona) consist of denser ($N > 10^{11}$ cm^{-3}) turbulent plasma, where the most of energy release takes place. This energy release takes place within the entire volume of the kernel with the maximum efficiency close to the surface of the kernel, where the kernels' wiggly magnetic field came in contact with the outside field. MHD turbulence keeps boiling within the kernel which leads to simplification of tangled magnetic field. There are many suitable points within the kernel volume where the field gradients are large and conductivity is turbulent hence the reconnection gets easier. As time progress, the field within the kernel simplifies, the plasma leaves kernel, some of it being snatched, some drained, some convected away and the kernel disappears. In the image sequence seen in Figure 5, the evolution of the "loop-summit" kernel shows its rise (phases **a-c**) most probably due to the upward force exerted on it by a system of up-winded loops crossing at the kernel. The kernel appears to split during the decay phase (**d-e**) together with the formation of the visible arcade. In frame (**f**), a loop like connection is formed between these two kernels (sketched) with the arms (rooted in these edge kernels) going far away (also drawn in frame (**h**).

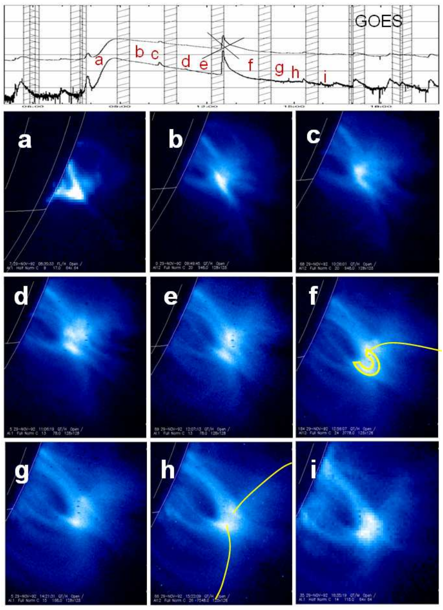


Figure 5: Evolution of the X-ray morphology of the C9.1 long duration limb flare as seen using Al12 *Yohkoh* SXT filters on 29 November 1992. On the upper *GOES* plot, the times of images are indicated.

Another example shown here has been observed by SXT on 21 September 1999 and its evolution is presented in Figure 6. Here also, kernel rise is observed (**a-b**), splitting into two (**b-c**), this time more vertical (in projection). The up-winded arms become filled with plasma, probably drawn from the kernel itself (**e-g**). The formation of "hanging arcade" with the bright edge kernels is seen around (**g-h**) with subsequent relaxation at (**i**). At this late phase down- and up-winding arms cross, as is schematically drawn on top. It appears from these and many other flare sequences studied that edge loop-top kernels are the root-points for the other (magnetic) connections. One of the most striking for us pattern of such magnetic rooting "via kernels" is shown in Figure 7. Here is seen in more details the transition of a longer structure connecting the opposite polarity regions of the atmosphere with the short, arcade-like bright emission patches at the foot-points. On the enlarged sequence, taken with cadence of few seconds, the root-points (circles) are seen to jump from one to the other

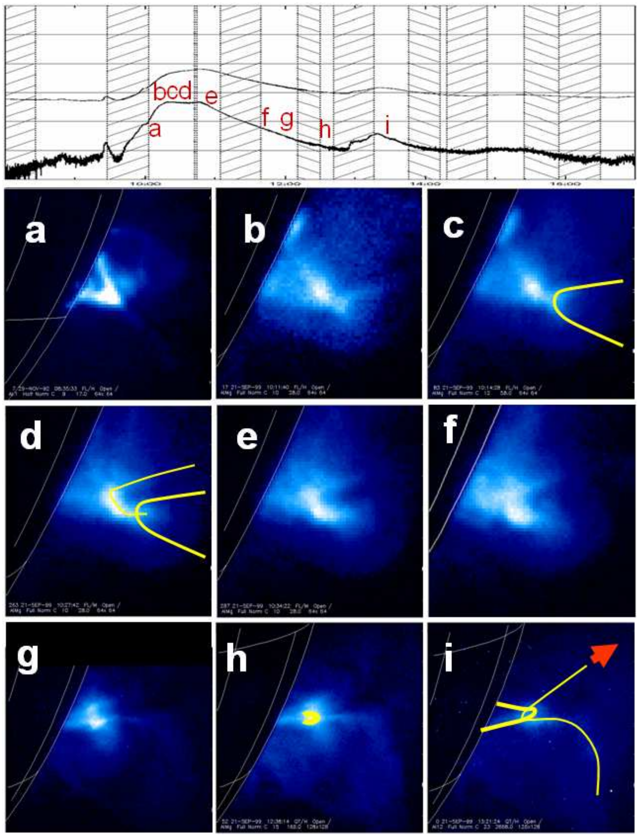


Figure 6: Evolution of the X-ray morphology of the C7 gradual rise and fall limb flare as seen using Al *Yohkoh* SXT filters on 21 September 1999. On the *GOES* plot, the times of images are indicated.

side of this footpoint arcade, as the event evolve, with the corresponding change of the brightness of the longer interconnecting loop. This may indicate that the interconnecting loop is actually composed of two near-parallel threads, rooted to a pair of edge kernels of the footpoint arcade. Even more illustrative in the context of “rooting” are images of protuberances, especially these, being “in eruption” where the expansion enlarges the substructures sometimes many times allowing to see them as through the magnifying glass. An example is presented in Figure 8. Here, the cool plasma resumes shapes of multiple nested arches, showing beautifully the sequence of “rooting” for at

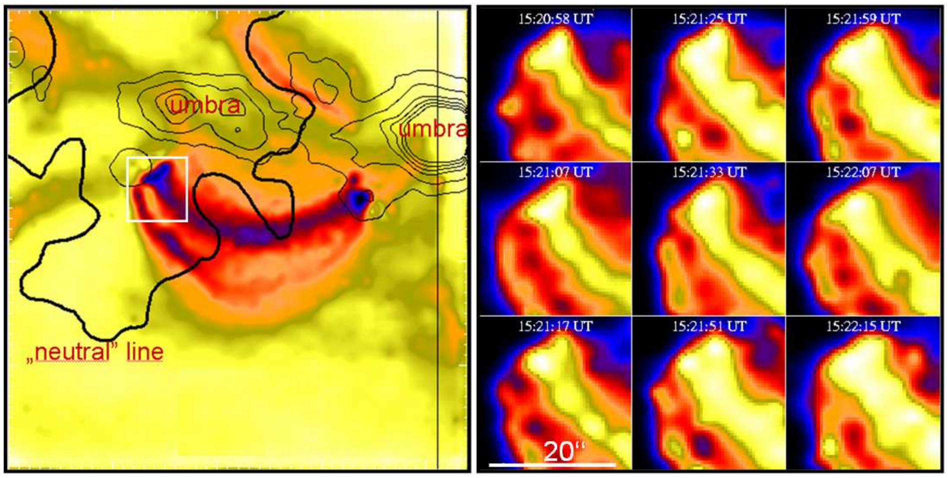


Figure 7: **Left:** The overlay of deconvolved SXT Al01 image (gray scale – dark indicates higher X-ray intensity) with the white light (SXT sensor) contour image. The SXT image represents the plasma being at the temperature above $\sim 2\,\mathrm{MK}$. The iso-contours indicate the umbrae locations. Deconvolved X-ray image represents the mean of 10 exposures taken over the period 15:20:57 UT – 15:22:20 UT on 11 July 1992 when the flare (prominent double loop) was in progress. Heavy line marks the "neutral line" shape as derived from the Marshall vertical magnetic field component. **Right:** Nine consecutive deconvolved SXT Be119 images (column order) for the indicated "foot-point" region of this flare. The size of individual sub-frame is 24.5 arcsec $\times$24.5 arcsec).

least three adjoining stages. It would be impossible to model this field line configuration by means of potential/force-free extrapolations from the photosphere. A particularly interesting feature is the splitting of the higher stage structures into branches at the endpoints (see magnified portions). Similar split-end branches are observed by *TRACE* as presented recently by Aschwanden and Title, (2004). The authors comment that the structures presented follow along dome-like and canopy-like configurations. Another striking example of the arcade-like configurations comes from the recent very high resolution observations of the photospheric G-band structures obtained using Swedish Vacuum Solar Telescope (SVST). In Figure 9, we present filtergrams taken in 488 nm light at the Swedish 1-meter Solar Telescope on the island of La Palma. The image in the right panel highlights the three-dimensional nature of the photosphere when seen at these large angles. The structures in the dark sunspots in the upper central area of the image show

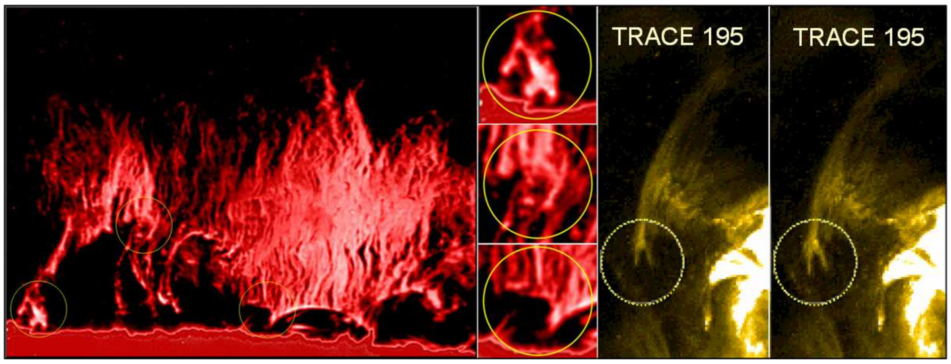


Figure 8: A small limb prominence about 50000 km high observed on 7 December 1970, showing the characteristic vertical structure which remains static while material flows downs through the magnetically defined filamentary tubes. These tubes are apparently "anchored" in the spine of the "lower stage" structure. The joints are presumably the plasma kernels where the magnetic field lines of the tube merge through the field lines of the spine. Picture was taken in Hα line. Enlarged are three regions in the picture showing the basic structures in more details. Courtesy: Sacramento Peak Observatory, John W. Evans Solar Facility (http://nsosp.nso.edu/esf/pics.html). Similar split-end branches are observed by *TRACE* (right two panels).

distinct elevation above the dark "floor" of the sunspot. The height of the structures has been estimated to be between 200 and 450 km (`http://www.lmsal.com/Press/SPD2003.html`). This is of particular interest to understand what is the nature of connection between these tiny, stage one magnetized systems with the overlying structures. In this respect studies of the highest resolution magnetograms (MDI), "chromospheric" and TRACE UV-EUV images are of particular interest. Rutten (1999), gives a nice review in this context, showing well-coaligned images in these ranges. A compilation made of two pictures from his paper is shown in Figure 10. MDI/*TRACE* comparison shows that the chromospheric emission pattern corresponds closely with the photospheric magnetic field pattern, irrespective of polarity. The bright chromospheric "speckles" overlie patches of positive or negative field concentrations in the photosphere. Speckles are somewhat asymmetric, resembling systems of tiny loops at the *TRACE* resolution, corresponding possibly to dark features from Figure 9 observed with much higher resolution. The brighter ones are arranged in chains looking like arcades. Even more convincing in this respect is the image

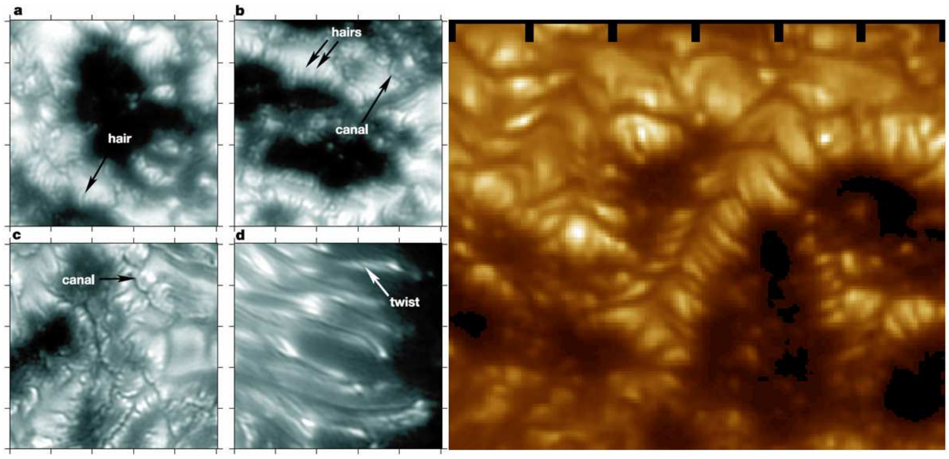


Figure 9: **Left:** Thin dark features in active region 10030 on 15 July 2002. For detailed description see Scharmer et. al., 2002. **Right:** Images of a solar active region taken on 24 July 2002 near the eastern limb of the Sun at heliographic coordinates S15 E53. The limb is towards the top of the image. The tick marks are 1000 km apart. The smallest resolvable features in the image are less than 100 km in size.

at `http://www.sunspot.noao.edu/sunspot/ dstwww/gifs/fill1.gif` Also reproduced on page 268 of Stix (1989) and in many other books. What is called by Rutten "as bright grain clusters in the Hα wings" might be actually a system of tiny canopies, forming **stage I** structures in our description. Similar impression provides the comparison between the G-band and overlying Ca II structures (Figure 10, bottom images). Here the diffuse patches of Ca II K network emission appear to consist of bright kernels and the net of diffuse links in between. Tendency to form arcades predominate the organization of brighter patches. So we conclude at this point that recent observations support the view of plasma being organized into systems of tiny canopies (arcades) of fluxropes joining opposite magnetic elements, as soon as they became visible from outside. Such organization is probably possible through establishing magnetic contacts across the arcade summits. This process involves the formation of turbulent kernels (of the cross-section < 100 km) at the photospheric level.

From the other global boundary of postulated, hierarchical organization of links in the solar atmosphere, the largest structures may be observed by the coronographs, with the overwhelming majority of data

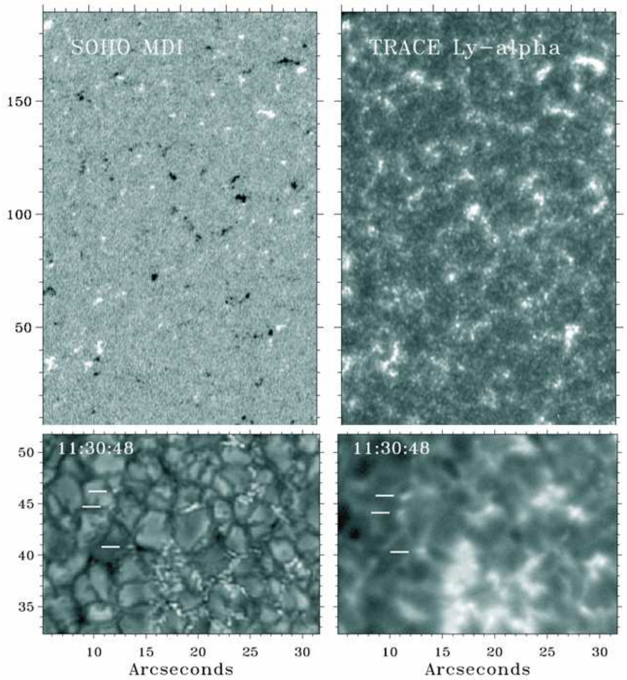


Figure 10: **Upper row:** Part of an MDI magnetogram and a co-aligned part of a simultaneous *TRACE* Lyα filtergram (right, from Rutten, 1999: Figure 1). **Lower row:** Part of a high-resolution (0.2 arcsec) G-band filtergram (bandpass 10 Å FWHM) from a sequence taken by R.A. Shine with the SVST and simultaneous Ca II K filtergram (bandpass 3 Å FWHM) of the same area (left, from Rutten, 1999: Figure 6).

collected by LASCO aboard *SOHO*. By looking through a large archive of the images presented in LASCO Gallery `http://lasco-www.nrl.navy.mil/public_images.html`, we selected a representative shown in Figure 11. Normally, the brightness of "guiet" corona is too low for their structures to be seen clearly above $\sim$2 solar radii, except some coronal helmets and rays. The plasma higher-up in the corona becomes visible during transient effects (different types of CME's) when denser structures are moving out of the Sun. In the Figure, a particular transient is seen, observed by C2 coronograph. On this and many other images of coronal transients, the moving plasma appears to be driven outwards by stretched magnetic configuration. Common impression is that the observed system behaves like slingshot in action with both the rubbers and the load outlined. As a consequence of looking through many of

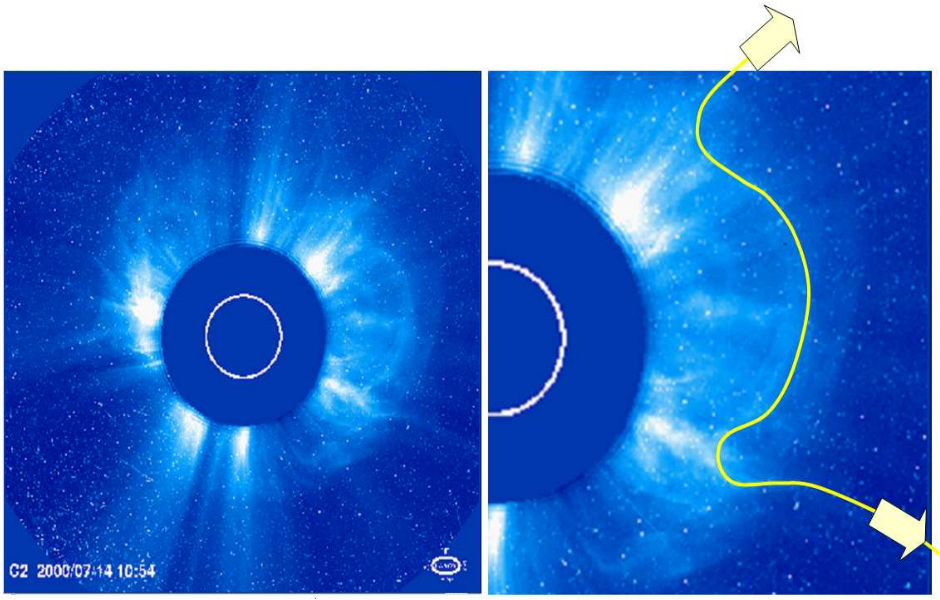


Figure 11: Observation of the large system of transient structure seen on 14 April 2000. The line drawn on an enlargement, represents a direct link between plasmas originating from active regions on both hemispheres. Envisaged stretching of the supporting magnetic field line is indicated (`http://lasco-www.nrl.navy.mil/images/000714_c2eit_sm.gif`).

images similar to those shown above, we came to the idea of hierarchical model of organization of links in the solar atmosphere. Description of this model in more details we start with the summary of properties of its basic constituting structure.

3. Basic structure

Observations tell us that the solar corona as seen in various spectral bands consists of the brigh/dark arcade-like structures. Their visibility is due to the increased pressure. From the many detailed observations of the solar structures, we arrived to the concept of hierarchical type of organization for the structures seen in the solar atmosphere. The concept is illustrated in Figure 12. In this model, we propose that the corona consists of numerous interlinked basic structures: "spiders". Within the body of elementary "spider" a number of distinctive plasma

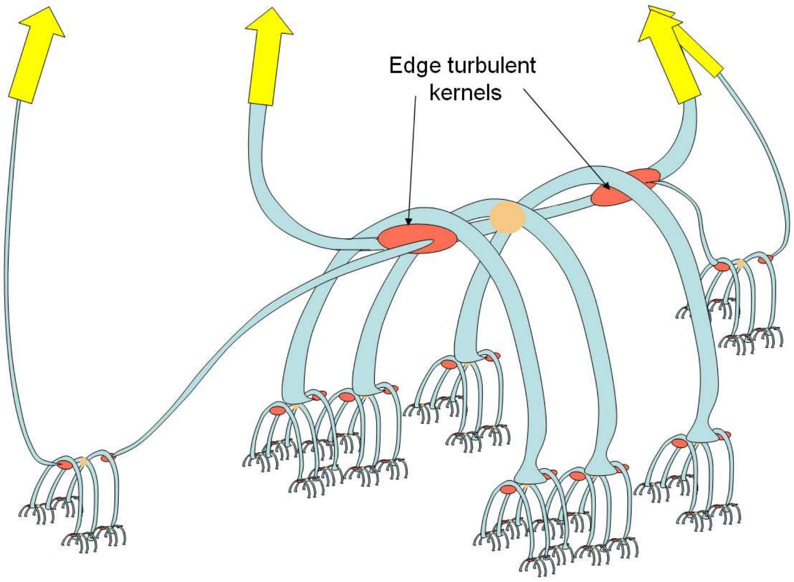


Figure 12: Proposed hierarchical structure of magnetic links in the visible atmosphere. The basic structure consists of kernels located along the arcade summits. The most active are the edge kernels within each arcade. The links to larger scale structures occur through edge kernels. Magnetic tension is represented by arrows.

kernels and links between them are present: legs are linking to lower structures (their kernels), arms to upper. There may be many legs in the spider (more in the smaller structures) and usually less (two) arms linking to the kernels of the structure above. Down-links provide rooting to below (eventually to magnetic elements) while up-links introduce upward stress (eventually through links to solar wind). The other, more detailed properties of the spiders are listed below.

1. Turbulent kernels at the edges of the spider are the most distinguished. They are the regions where links from "above" are rooted. Edge kernels are places of efficient reconnection, where the energy stored in stressed magnetic configuration is disposed off most efficiently.
2. Active kernels at the edge of the arcade are the locations of direct

joints of the spider with the overlying higher structures. In this way the hierarchy is build-up: legs (loop roots) of a higher structures are anchored in the edge kernels of the lower structures.

3. Individual spider "limbs" are going mostly downwards. Opposite limbs form classical arcade-like structures, with the spine (arcade channel) running immediately below the loop summits. Legs originating from edge kernels are usually the best seen as they provide the most direct contacts from regions of efficient energy deposition. They connect with denser kernels below, providing channels for filling the edge kernels with plasma (through a kind of evaporation process – between kernels). Following filling of the entire spider depends on efficiency of horizontal links along the arcade channel.

4. Turbulent kernels (secondary) can be seen everywhere along the arcade. Links between them and the edge kernels allow for some plasma and energy transport "across" the arcade. Secondary kernels are the roots of arcade rays ("downflows to arcade") seen sometimes on the TRACE and (overexposed) SXT images and form the end-points of "draperies" (see Figure 8).

5. Secondary kernels constitute the plasma source for down-flows through associated arcade legs. The entire spider plasma may eventually drain through them. This persistent downflows are easy to observe in EUV and visible spectra.

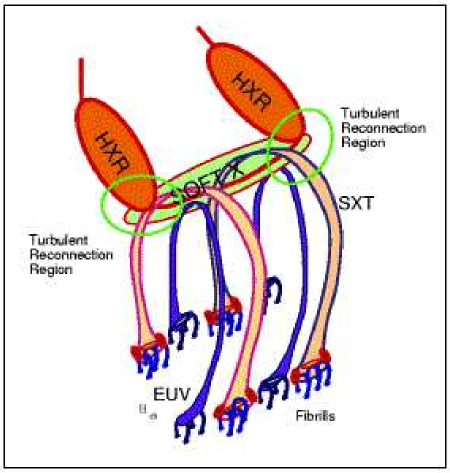
6. Kernels are the primary locations where reconnection takes place at the realistic rates. The reconnection rate depends most probably on the tension of magnetic stresses within the kernel. Increased magnetic stresses are balanced by higher gas pressure inside the kernel.

7. A hard X-ray sources are located along the arms going up from the edge kernels at its surface (its transition region).

8. The overall structure is globally stretched outwards due to interaction with the fast solar wind. This stretching is "transported" down within the hierarchy, with the most of stress occurring at the edge joints.

9. Owing to its frequent (overwhelming) presence everywhere in the atmosphere, spider may presumably represent a stable somewhat relaxed configuration of the magnetized rotationally stressed system. In this case the spider configuration might represent the low energy quasi-steady-state arrangement.

As concerns the plasma condition inside the turbulent kernel, we refer to the model presented by Jakimiec et al., (1998). For more details see also `http://solarmuri.ssl.berkeley. edu/~hhudson/cartoons/thepages/Jakimiec.html`. Within



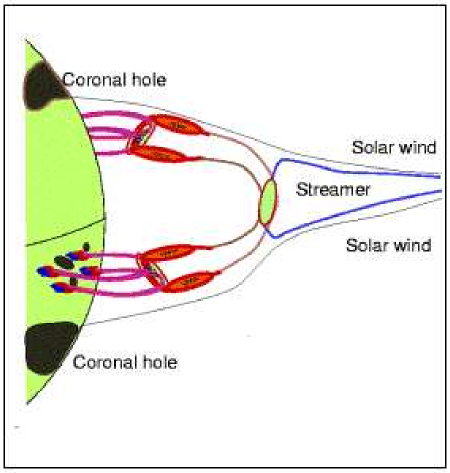


Figure 13: Simplified configuration of magnetic fiels in hierarchical model in the lower and upper corona.

the hierarchical equatorial structure, 6 – 7 distinct stages can be identified. Each of the stages may relate to particular solar phenomenon. In Table 1, we name and list these stages and present their basic properties.

In the turbulent kernel, magnetic field is very complicated, with the magnetic field lines strongly braided, like in skein. This effectively isolates the kernel from the surrounding atmosphere allowing it to resume symmetric shape. The plasma contained in the kernel is compressed. The only transport is allowed along those few field lines which escape outside through legs and arms. Those escaping field lines provide links to the other kernels. The filling factor in the kernel is expected to be nearly one, dropping dramatically at the edges. One can think of a bunch of magnetic field lines which emerge from particular kernel with a given mass, volume and temperature. Through each emerging field line, a stretching force (magnetic tension) acts on the entire kernel. Kernel's position and dynamics result from the balance of all such forces and the gravity. If those forces are not balanced, entire kernels may move respective each other in a complicated way. For those pairs being directly linked, this relative motion may result in acceleration/deceleration (heating/cooling) of the particles fixed to connecting field lines. Magnetic mirroring of particles trapped in the portion of "local atmosphere" between linked kernels is easy to imagine. The hard X-rays may came as a result of the precipitation of accelerated particles escaping from the loss cone and penetrating the surface of an associated denser kernel. This might be an equivalent of the classical scenario of high energy particles penetrating the dense transition region of a classical loop. The role of the photosphere is resumed in this case by the dense plasma contained in the kernel, and the propagation of accelerated particles takes place along the arm(s) connecting the kernel to the other one in a hierarchical system. Inside the kernel, the conditions are expected to be close to thermal, but not necessarily isothermal as the heating rate might be distributed within the kernel in many ways. Plasma flows between kernels may also take place provided necessary pressure and/or potential energy differences exist along interconnecting channels. This flows may lead to a slow filling of the spider system through the chain of most active kernels along the way to the tiniest one linked directly to dense plasma in the photospheric magnetic element. This staged filling may be taught as a counterpart of classical *evaporation*.

4. The Hierarchy

Probably the best illustration of the hierarchical nature of the links in solar atmosphere is presented in Figure 6 with the schematic diagram shown in Figure 12. Many of the larger scale coronal structures can only be seen "in transition", as the plasma cools down and condenses, after the heating in respective turbulent kernels is ceased (revealing in this way more than one stage). Many of them reveal similar internal pattern, independent of the length scale.

Following our earlier considerations (Sylwester and Sylwester, 1998a, Sylwester, 1999), we postulate here that most of the corona is organized in a hierarchical net of magnetic links extending from the levels just below the photosphere up to the interplanetary space. This concept, illustrated in Figure 12 is extended to links between the magnetically closed portion of the solar atmosphere (forming one equatorial hierarchical system) and the regions of fast solar wind originating from coronal holes in Figure 13.

As concerns dynamics, the reconfiguration of stage I structures is the fastest with the typical correlation times of minutes. On the largest scale, typical life-time of a global configuration constitute a fraction of solar cycle. Constant reconfiguration is however a basic property of the entire structure.

Table 1: Characteristic stages and scales of spiders in a global equatorial hierarchical structure

stage	size/width [km]	feature	location	$log\, N$ [cm^{-3}]	T [MK]
I	300/50	phot.filament	photosphere	15	0.006
II	3000/500	blinkers, spicules	trans. region	11-13	0.006-0.1
III	10000/2000	moss, brigt points	trans. region	9-10	0.5-1
IV	50000/10000	coronal loops	(low) corona	8-9	1-5
		(post) flaring	(low) corona	10-12	5-30
V	150000/10000	AR interconnecting	corona	7-8	2-5
VI	500000/10000	transequatorial	corona	6-8	2-3
VII	global	streamers	upper corona	4-6	1-2

At any time, reconnection simplify the magnetic configuration in some kernels braking some links, and creating new interconnections, the plasma contained spreads along the field lines. A new kernels are created as the new magnetic flux emerge from below. Some field lines, closing within the structure, those close to the envelope current sheet recombine to fast solar wind gaining tension from the solar wind plasma expanding into heliosphere. This picture, if real, elucidate that the plasma system (under the envelope) undergoing constant stresses is in a chaotic transient equilibrium state (self-organized criticality) like in a sandpile. The smallest disturbance (recombination – tether-cutting) may lead to catastrophic energy release (flare, CME) involving a part (up to total) of the energy contained in stressed system. Smaller, of local importance, energy releases (micro-flares, chromospheric explosions, various brightenings etc.) are much more common (power law with the exponent $\sim$2, Hughes et. al., 2003), like in any self-organized system in the critical equilibrium.

The solar atmosphere can easily be imagined as the forced system where solar magnetic fields are subject to permanent stress from below (due to convective motions in photosphere) and above (large scale reconfigurations on the closed/open field boundaries). If such description is indeed appropriate for the solar atmosphere, the consequences of such a system of self-organized links are far-reaching.

One may ask: Single loops are generally well seen - don't they? This is easy to imagine that one of the edge kernels is dominant, filing preferentially only one side of the spider. In this case a structure resembling a single loop would be seen, except with the brighter thermal kernel at the summit - just the picture observed by SXT.

5. Summary and Conclusions

It is among the most deeply rooted beliefs among solar physicist that the solar upper atmosphere consists of a number of magnetic loop-like structures rooted directly in individual magnetic unipolar elements present at the photospheric level. However, the images presented and discussed in this paper show that in numerous cases, a "standard single loop" model of magnetic field organization in solar atmosphere is certainly not an adequate description of the complexity seen. We attempt to illustrate a different model of plasma–magnetic field structuring in the atmosphere. In the proposed pattern, direct, longer distance conductive links between coronal and photospheric plasmas are prohibited, in the contrary to the "single loop scenario". The inferences drawn here may have important consequences for understanding the behaviour of every portion of solar atmosphere.

Our model appears distinct from those yet suggested and contained in the "Grand Archive of Flare and CME Cartoons" at `http://solarmuri.ssl.berkeley.edu/~hhudson/cartoons/`.

Some indirect associations can be traced to models of Vlahos, (1993) `http://solarmuri.ssl.berkeley.edu/ ~hhudson/cartoons/thepages/Vlahos.html`

and Gary-Moore, 2004 `http://solarmuri.ssl.berkeley.edu/~hhudson/cartoons/thepages/Gary-Moore.html`

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Izlaganje sa znanstvenog skupa

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