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(IM)BALANCE OF FORCES IN THE CORONA

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Abstract. Observed pattern of variability of solar atmosphere plasma structures, often accompanied by respective measured Doppler shifts, provides a direct evidence of imbalanced forces acting in this environment. Observed motions have been studied in various energy bands, extending from radio to hard X-rays using ground and space-borne instruments. Here, we present the results of a dedicated study of present observational databases in selected energy ranges with a special interest focused on *TRACE* movies. In our search we included also recently released wavelet-processed EIT and LASCO movies (from *SOHO*) as they provide additional support to the conclusions of this study.
The main outcome of the work performed is our better understanding of a basic role played by plasma kernels in every "layer" of the solar atmosphere. These kernels appear to be present, and rapidly evolve at the locations of violent (intense) energy release locations. Subsequent formation of a more stable coronal magnetic structures seen in the form of "spiders" or "scorpions" is due to self-reorganization of plasma kernels. It comes out that the spider structure represents a basic, quasi-equilibrium building block of the solar atmosphere. When observed in a particular image, within a limited energy band, i.e. optical, EUV, soft or hard X-rays, only a part of this spider plasma structure can usually be seen, noticeably resembling a loop-like structure with a brighter top, or an arcade of loops connected along the ridge of summit kernels, or seemingly isolated oval source. This energy-dependent visibility effects caused a general confusion present in solar physics and led to proliferation of a simple fluxtube scenarios.

In our study presented herewith, we used the images obtained with the best available resolution, being enhanced numerically where possible. For the first time we enhanced the *TRACE* image datacube in a systematic way for a particular flare. Based on the results of analysis of a large number of images, we push forward a qualitative *toy* model of atmospheric connectivity pattern (Sylwester, J. and Sylwester, B., 2004). This hierarchic model is able to handle in a natural way observed complexity of atmospheric phenomena. Here, we discuss to some extend verifiable predictions of the hierarchical model outlining a number of new studies which might prove the concept. These predictions arise concurently with the first data coming down from new missions being recently launched into orbit: the *Hinode* and the *Stereo*.

Key words: Solar corona - plasma kernels - dynamics - hierarchical order

1. Introduction

Over the years, we came across over many solar patterns as observed in radio, optical, EUV, and X-ray bands. With the increasing spatial and temporal resolution of these images, we felt growing discomfort driven by growing lack of harmony between the complexity of the observed phenomena (like protuberances, CMEs, flares seen in Hα and in EUV etc.) and the simplicity of the schematic models, providing the framework for physical interpretation of the observations. Of the most discomforting assumption being made generally was the one concerning the shape of magnetic field above the granulation. In the most of cases the observed pattern of emission in the higher, magnetically dominated portion of the solar atmosphere is assumed to be well described by "smooth" extrapolations (Schrijver at al, 2006) of the observed magnetic fields, using force-free or potential approximations. Impressive resemblance of the post-flare EIT or *TRACE* structures observed extending high into the corona with the extrapolated field lines is taken as evidence of generality of the concept, camouflaging a real complexity of the plasma confinement at the limit of the instrument resolution.

In this study we looked into details, and would like to illustrate our findings on few examples. In order to see at the resolution limit of present instruments, we based our study on the images obtained during the best viewing conditions and made numerical de-blurring by means of deconvolution where possible. In the case of *Yohkoh* SXT images, we used ANDRIL algorithm as described by Sylwester and Sylwester (1999). We also attempted for the first time to incorporate ANDRIL into de-blurring of *TRACE* EUV images. Some details of this attempt are described below.

2. *TRACE* deconvolution

In order to perform the deconvolution of *TRACE* images, we generated the point spread function (PSF) 2^{d} shape using the *SolarSoft* package `ssw/trace /idl/util/trace_psf_isothermal.pro` developed recently by Gburek, Sylwester and Martens (2006). To simplify the calculation, we assumed that the plasma temperature is equal to $T = 1$ MK everywhere over the image. This assumption does not influence the results of deconvolution for images where no saturation of the image is observed. This was the case for the images studied below. A "simple" one-to-one deconvolution (i.e. no oversampling) has been used which limits the computation time to approximately 1 hour per image on a standard PC. We took the footprint of the PSF area to cover the entire subimage undergoing deconvolution (~ 150 pixels). i.e. we nearly entirely removed the diffraction and the instrumental blur. Some image pre-cleaning has been applied in order to remove the tracks from the flare-related energetic particles hitting the CCD. The deconvolution has been performed using the ANDRIL engine (Sylwester and Sylwester, 1999), a part of the *SolarSoft* package. As a result of deconvolution, the contrast on the images increases by at least a factor of two revealing presence of structures with the sizes of a single 0.5 arcsec pixel (~ 400 km on the Sun). A major influence for the results of this study had an inspection

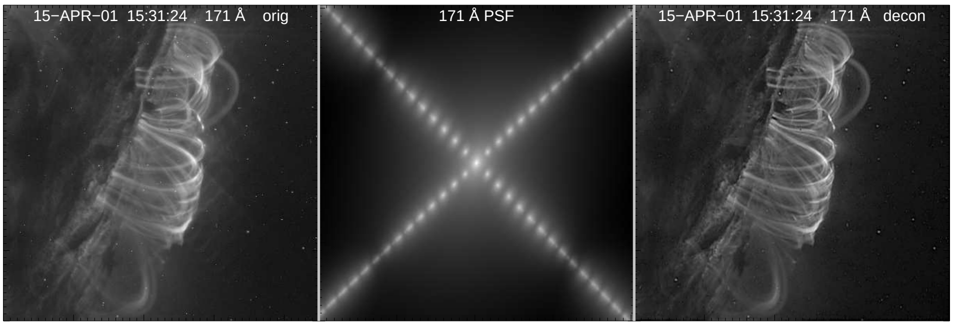

Figure 1: An example of *TRACE* deconvolution performance. The left image represents a directly observed intensity pattern with the effects of the instrument blur showing-up. The most prominent are multiple diffraction crests accompanying the brightest sources. The right panel shows corresponding de-blurred image and the point spread function (PSF) is represented in the central image. The PSF shape has been calculated using the *SolarSoft* package. Logarithmic intensity scaling has been applied in order to comply with a large dynamical range of brightness variation across the images and PSF.

of the *TRACE* Flare Catalogue (`http://hea-www.harvard.edu/trace/`) containing hundreds of flare movies. The Catalogue has been prepared by the SAO *TRACE* Team. We searched through hundreds of these movies and selected one particular event as an example: the 2002 May 27, M2.0 flare seen close to western limb around 16:10 UT. The flare has been imaged by *TRACE* in a rapid cadence (9 s) of 195 Å filter exposures, covering the entire rise, maximum and the decay phase. We decided to made deconvolution of all available images (~ 150) in order to see the evolution of smallest features, with sizes down to a single pixel. Some pre-deconvolution cleaning has been applied as towards the end of the sequence, the raw images were badly contaminated with the particle background coming from the high-energy particles associated with this event. The event has been well-observed by *RHESSI*, and the work is in progress on *RHESSI-TRACE* image co-alignment. The evolution of plasma structures associated with this flare is illustrated on a selection of deconvolved images presented in Figure 2. The first image represents the pre-flare situation, and the cadence of the im-

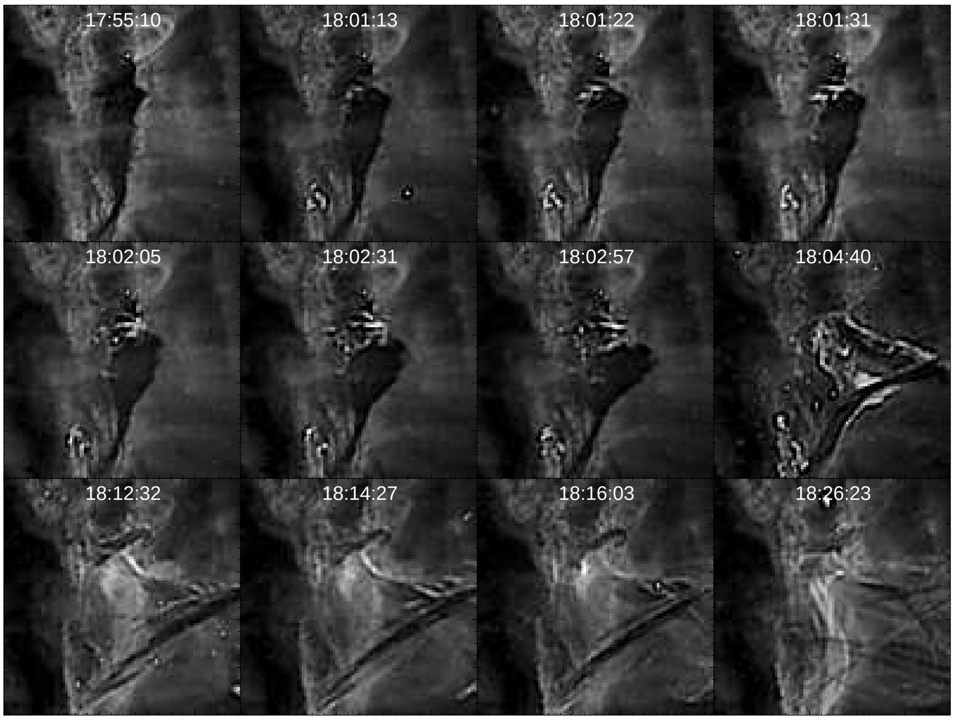

Figure 2: A sequence of deconvolved *TRACE* 195 Å images of 2002 May 27 M2.0 flare. The logarithmic scaling of brightness has been applied for individual images in order to bring the visibility of fainter details. The spatial extend of each image is 30000 $\times$30000?? km on the Sun.

ages shown during the rise phase is 9 s. It is seen that the flare, as seen with the 195 Å filter begins as a brightening of a pair of compact sources at the middle-top and a number of compact sources at the bottom left. Later on (18:01:22 UT), the middle sources dominate the emission and become linked forming a pair of "triple" compact formations. Around 18:02:57 UT a disruption of magnetic links within this "triplet" probably took place leading to a fast acceleration, motion and brightening of a dark "filament". The disruption was immediately proceeded by formation of a very bright, thin horizontal structure. The character of dynamic evolution suggests rather stretching or dragging of the plasma, not the explosion! It is seen that even a 10 s cadence is to slow for the details of very fast rearrangement to be followed during the flare rise phase. Everywhere throughout the evolution

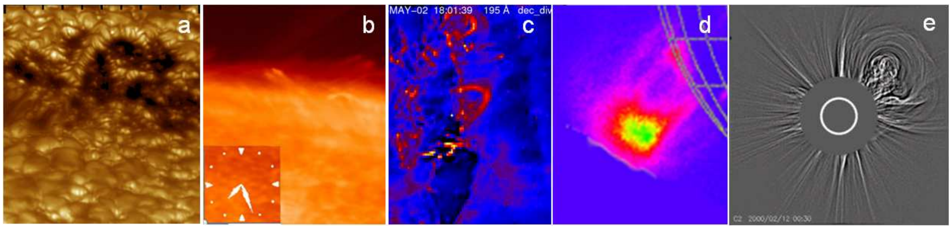

Figure 3: Kernels as seen in different "layers" in the solar atmosphere. Frames have been cut-out from images obtained by
a: SSVT `http://www.lmsal.com/Press/24jul02_gcont_ai.jpg`;
b: portion of an early frame form the SOT movie: Eruption above the Sun spot observed in Ca II H (397 nm), released by *Hinode* Team `http://antwrp.gsfc.nasa.gov/apod/ap061204.html`;
c: deconvolved *TRACE* image of the date indicated;
d: - the SPIRIT image
`http://www.cbk.pan.wroc.pl/RRS_conference/secret/presentations`
`/Slemzin/Multiwvl_spirit.ppt`;
e: wavelet transformed LASCO image
`http://lasco-www.nrl.navy.mil/index.php?p=content/wavelet`
The scales in frames are growing from left to right, in such a way, that the smallest recognizable details are $\sim$ 70 km and $\sim$ 500 km on a and b respectively. Projected height of the *TRACE* loop-like structures in the central image is $\sim$ 4200 km, and the height of the spider is $\sim$ 220 000 km. The size of the occulted Sun is drown as white circle on LASCO image.

of this event, it can be observed that the structures seen actually are formed of localized emission centers (kernels), all of them joined together by links of a smaller contrast. These links connect to individual kernels at various angles reflecting, most probably, the pattern of magnetic connectivity, as the plasma is "frozen in" because of its high conductivity. If so, observed

geometry of the magnetic links can not be accommodated within a framework of simple photospheric magnetic field extrapolations.
Towards the end of the event, a number of dark, thin and wiggly filaments are crossing the deconvolved area. Many of them appear to bent sharply and/or split.

Analysis of these shown and numerous other flare sequences led us to consider localized compact plasma structures i.e. kernels to be an predominant element of atmospheric structuring present in dynamic as well as a slowly evolving circumstances. In the following we will discuss the properties of the kernels and unveil their anticipated significance.

3. Plasma kernel properties

Previously available lower resolution images of solar atmospheric structures allowed in the most cases studies of a more quiet evolution pattern as the fine details were smoothed out by the instrument blur and cadences were slow. So overwhelming number of existing observations were reflecting a quasi-stationary patterns, revealing the form of magnetic connectivity arrangement for conditions close to equilibrium, when the forces acting on plasma are locally balanced. With a number of higher resolution images available now, let us outline a number of characteristic morphological properties of the plasma structures being in quasi-equilibrium. The basic constituent of the atmosphere is the turbulent plasma kernel (Jakimiec, 2002).

The kernel's physical identity is kept together by the inside tangled magnetic field. On the kernel surface envisaged are areas (kernel-spots: *k-spots*) where magnetic field lines enter/leaves the kernel. There appears to be usually more than three *k-spots* present, providing magnetic links to three other kernels, sometimes placed far apart. Magnetic tension of these links exert forces pulling the kernel in respective directions. In equilibrium, these forces, including the gravity and pressure, are balanced. Characteristic values of kernel's thermodynamic parameters are given by Sylwester, B. and Sylwester, J. (2007).

Stationary conditions When observed in a highest resolution, the quasi-equilibrium structures of the solar atmosphere also appear to consist of tiny linked elements with the spatial cross extent at the limit of present imagery. This is visible in a few examples shown in Figure 3 and the other examples presented in our earlier paper (Sylwester, J. and Sylwester, B. 2004). The characteristic sizes, plasma temperatures and densities of these elements depend on their proximity to the Sun. For those forming arcade-like structures in vicinity of sunspots (cf. Figure 3a), their sizes are 50-100 km, the temperatures are few thousand degrees and the densities correspond to densities of the classical photosphere-chromosphere model at comparable heights. Somewhat higher-up, as seen on *TRACE* images, the individual kernels became evident, located at the "roots" or "footpoints" of respective thin coronal loops (active region or post-flare) extending high into the corona, the kernel sizes become larger, few hundred kilometers across, temperatures T higher, in the range $5\,10^4 - 10^6$ K. In the corona, as seen in X-rays and in EUV for the post-flaring loops, the summit kernels are of 1000-3000 km cross-section, $T \sim 1$ MK and densities $N_e \sim 10^9 - 10^{11}$ cm^{-3}. As found by Pres and Kolomanski (2007), the properties of X-ray kernels scale with the height in the corona, in particular, their diameters grow with height. Kernels are seen to be linked and these links frequently form double strands sometimes helically winded. It is observed, that the most stable arrangement, frequently seen for protuberances or slowly evolving system of post-flare "loops", is of the spider type. The spider (cf. Figure 5, right panel), first discussed by Sylwester, J. and Sylwester, B. (2004), consists of two or more near-by coupled kernels at a given height (forming sometimes so-called arcade channel: backbone) which are linked to the other kernels at lower heights (legs) and to the kernels higher-up in the atmosphere (arms). Spiders at different heights are interlinked forming a hierarchical pattern of (magnetic) connections sometimes visible when filled with plasma. Such a system appears to be, by yet unknown reason, the most stable stressed magnetized plasma configuration. Most probably it represents a system of minimum energy configuration forming a fractal type arrangement of several stages (levels). In the spider at a given level (the height of the backbone is important) regions of more active energy release develop at these kernels (usually edge ones) equipped with arms connecting up. Less active (quiet) are kernels joining preferentially down. These are placed along the backbone and their legs often form an arcade. Differences in the energy release rates between active and quiet kernels give probably rise to observed plasma circulation. The active kernels draw up the matter from a lower kernels through "evaporation" with its following transfer along the backbone towards the quiet kernels. Once there, plasma cools and drain down towards a different set of the lower lying kernels. Such plasma circulation has to be supported by respective magnetic field rearrangement. The most of magnetic flux entering into the lower level kernels is also circulated up and down in such a way that it is effectively being removed after "processing". The circulation might be possible as a consequence of constant rearrangement of magnetic field within kernels through the turbulent reconnection. Otherwise, any transport of plasma across magnetic field would be prohibited due to its very high conductivity. As seen along the backbone, circulation might resemble slip-running reconnection along the backbone. After "processing", only a small part of magnetic flux is left to enter into the upper level kernels through arms. Probably this corresponds to a part of magnetic flux for which the complete recycling is not possible for some reason (violation of helicity conservation?). This type of plasma and magnetic field "recycling" within the spider is being postulated in our model to hold-up across many (4-6) stages forming the global hierarchy of atmospheric structuring.

In this hierarchical model, it is rather unexpected that a *direct* magnetic link between elementary magnetic intergranular elements and the corona exists. Instead, the magnetic field line connecting the coronal portion of the atmosphere is expected to enter a number of lower lying kernels on the way to upper corona. It is extremely tangled inside these kernels. It is therefore inappropriate within this model to think of a "smooth" geometry of a field line linking corona with a given elementary sub-surface magnetic flux tube. A more appropriate appears a picture where the most of plasma is concentrated into a magnetically-confined kernels and the remaining part fills those magnetic fields which connect the kernels. In this respect helpful might be a concept of a kernel possessing spots - *k-spots* (analog to sunspots) where the magnetic field lines cross its surface. So the kernel is a turbulent magnetized plasma entity with most of the field lines tangled inside and some crossing the surface through *k-spots.* The magnetic field inside the kernel should be able to keep the kernel plasma together. The inside field is expected to be very tangled, with small characteristic radii of curvature – much smaller than the size of the kernel. This curvature forces increase magnetic pressure towards the kernel center, and keeps kernel plasma together. Due to reconnection which is expected to happen most efficiently close to the kernel skin (Jakimiec, 2002), the pattern of fields on the boundary between the inside and outside also dynamically rearranges, allowing some of the field lines to leave, some to enter bringing in and out some of the frozen-in plasma.

In a prevailing, steady conditions, the kernels are arranging themselves into a system of interlinked spiders, where stresses due to constant motions of underlying intergranular magnetic elements are being removed by plasma "circulation". However, such constantly stressed system is expected to be in a state of self-organized criticality (Lu and Hamilton, 1991), subject to infrequent catastrophic rearrangements. During these rearrangements, a transient, non-stationary processes take place, described in more details below. In the steady conditions, a constant energy supply to the system is taking place from below through the activity of the underlying magnetic elements, subject to convection driven random walk (a complete "magnetic carpet" flux being replenished each 1-2 days, Close et al., 2004).

Non-stationary

Let us suppose that somewhere within the stressed hierarchical system, a rearrangement takes place between a pair of kernels (cf. Figure 2, frames: 18:01:21 and 18:02:05). If this disruption concerns a vital magnetic connection, non-equilibrium of forces arise, respective kernels accelerate and the connectivity pattern undergoes a fast rearrangement. This could lead to CME launch(es) and/or flare initiation accompanied with a release of substantial free magnetic energy pre-stored in a pre-disruption stressed configuration. The larger is the scale of rearrangement following the disruption, the greater is the amount of energy release. As illustrated in Figure 2 (after 18:02:31), following the disruption, some kernels are driven by imbalanced magnetic forces along different paths, sometimes wiggly or zig-zag, often being brought high-up into the corona. Sometimes, an internal structure of compacted pre-disruption kernel plasma is visible, like in a magnifying glass, after being lifted-up to the corona. Some kernels are being teared up by the imbalanced magnetic tension forces. Described scenario is illustrated in Figure 4. The breakout of important magnetic link leads to imbalance of the forces acting on involved kernels and some of them begin to approach as indicated in Figure 4 for the central kernel. This is followed by a collapse of this part of the atmosphere which is magnetically common between approaching kernels, i.e. this encompassed by field lines joining both kernels. Approaching kernels can eventually merge in case a new stable configuration is not reached earlier. In this concept, particles in such collapsing magnetic trap are being (Fermi) accelerated in a natural way, however the plasma will thermalize fast. Particles in the parts of the atmosphere between diverging kernels will also be (betatron) accelerated. In this case, the plasma will get rarified, and non-thermal conditions may prevail longer, at least as

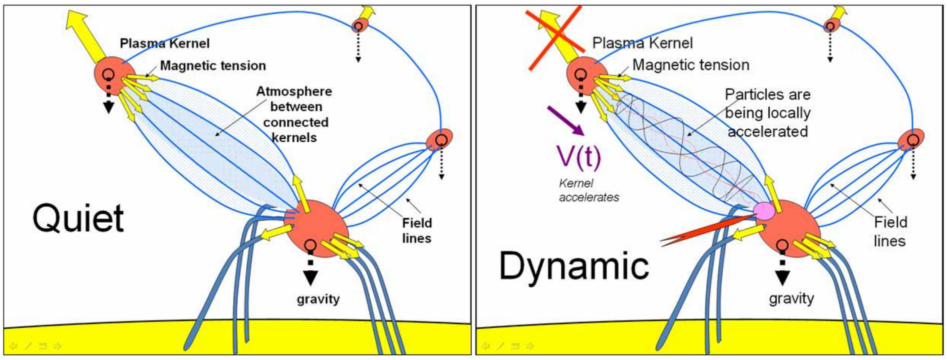

Figure 4: A scheme showing the concept of a break-out of vital magnetic link in a stressed (Quiet) configuration of coronal kernels. Following a breakout (Dynamic, upper-left, crossed-out), an important magnetic link is missing and system of kernels undergoes dynamic rearrangement. As a consequence particle acceleration takes place (see the text for more details).

long as the kernels are moving apart. In case that the kernel constitutes a part of a global net, its motion brings both converging and diverging scenarios into action at the same time, however in somewhat separated volumes. Depending on the magnetic boundary conditions holding the net in place, a new steady state may be reached without kernels merger. In case of a disruption of magnetically strong link, violent accelerations take place and kernels collision is unavoidable. Such a collision may cause following catastrophic rearrangements in a kind of chain reaction leading to gross rearrangement of a stressed magnetic kernel system being previously in the state of self-organized criticality. This rearrangement corresponds to the global catastrophe and release of large amount of pre-stored energy in the form of flare and/or CME, plasma bulk motions, waves or torsion. Even in a "quiet" state, which is always of finite duration, intermediate between flares, kernels are expected to oscillate relative to their minimum energy locations. One may find an analogy of this net of kernels with a system of weights placed in a 3D net of springs. Some weights will resonate and therefore waves may bring energy from one point of the system to the other in non-local way. In an analogy to this picture, observations of individual kernel oscillations should permit an insight into the magnitude of magnetic stresses operating locally in the plasma. Some resonant frequencies can probably be identified leading to a better diagnostics of plasma and magnetic conditions also within the links between the kernels. Some of the oscillatory nature of magnetic structures have already been investigated (Wang, 2006; Wang et al., 2007). It should be noted that within a proposed scenario, reconnection is taking place all the time in every kernel, leading to a constant plasma recycling. However in a quasi stationary mode this results in a slight imbalance of forces in the most cases, followed by a slow rearrangement. In this case the particle acceleration is not energetically dominant, although always present. In respect with the non-thermal signatures are can be way below the threshold of present instruments, in a domain of nano-flares.

In case of a vital magnetic link disruption, similar to that seen in Figure 2 and schematically presented in Figure 4, some of the accelerated energetic particles will penetrate into the denser kernels. They will loose their energy in bremsstrahlung hard X-ray emission in the area of *k-spots*, producing thick target emission. Some will however be kept inside a magnetic trap which is naturally formed between the approaching kernels. In this way a thin-target emission will arise. In this scenario it is envisioned , that a small number of the kernels are directly linked to kernels located much higher in the corona, sometimes being embedded in the solar wind. Acceleration inside such very narrow elongated magnetic channels may give rise to type III radiation.

The pattern of magnetic links between kernels is constantly evolving, being driven by permanent chaotic input coming from below (magnetic carpet). Magnetic elements of the carpet are the real roots of the system in the sense that they link to the magnetic field crossing the layer of granular convection. Sunspots are not a part of this carpet and therefore no substantial activity is expected from areas immediately above the sunspot umbrae. At the sunspot's periphery, at the outer edge of the penumbra, a vigorous activity is taking place leading to slow erosion of the sunspot magnetic structure.

The strongest magnetic forces are expected to act between kernels located at heights corresponding to classical chromosphere and low corona (close to "transition region"). For the lower-placed numerous spiders which are fast-evolving (blinkers?, Harrison, 1997) the rearrangement is mostly quasi-stationary. The higher spider structures link these numerous lowest level kernels with a much fewer (order of magnitude) second level kernels (spicules?) and only third or fourth level kernels are up into the corona. The strength of the links is decreasing along with decreasing overall strength of

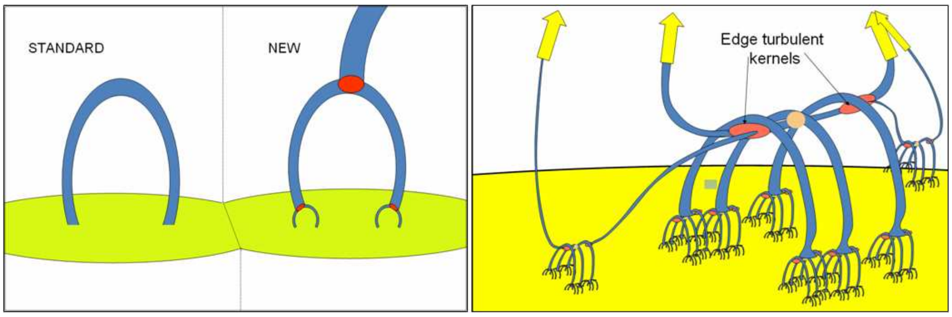

Figure 5: A scheme showing the difference between the standard and suggested new way of thinking on the links in magnetized plasma (left pair). Envisaged new 3^{d} picture of magnetic links is shown to the right (from Sylwester, J. and Sylwester, B., 2004).

the field (few times at each stage), but inversely increasing with the number of kernels at the given stage. Therefore, braking of the links between kernels at the third-fourth stage ("transition region" and lower corona) may lead to the most violent energy releases. It is to note, that the kernels motions after such disruptions may be oriented not only in the radial direction. However, disruption of the vertical strong magnetic links can lead to a fast downward motion of plasma kernel. This in turn can lead to formation of Moreton waves when collision of the kernel with the surface takes place.

Motions of plasma kernels are usually guided by the stronger field, but always appear to have at least three connection points with the other outside kernels. This can be easily seen on the first SOT movies just released by *Hinode* Team `http://antwrp.gsfc.nasa.gov/apod/ap061204.html`

In many instances, it is observed that quite separated regions of the solar atmosphere, even being on the opposite hemispheres, brighten simultaneously in EUV or X-rays. These may be a signature of interacting far away kernels being linked magnetically. In this case a condition has been reached (after appropriate sequence of reconnections) for the exchange of the magnetic field rooted within activated kernels. The atmosphere "locked" between them becomes a collapsing trap. As a consequence some plasma is being dragged out of the kernels, particles are being accelerated with some of their energy precipitating into the kernel.

4. Conclusions

Presented and discussed observational material forced us to revise our understanding of connectivity pattern in the corona. In particular a basic paradigm of solar physics, i.e. a simple magnetic loop concept (cf. Figure 5, left), where coronal loops are a *direct* extension of magnetic fluxtubes seen on the solar surface has to be reconsidered. We envisage and in many case see directly a cascade of denser-than-surrounding plasma kernels magnetically interlinked, forming so-called spiders. In the most cases these spiders quite closely resembles a dipole field pattern, when observed with insufficient spatial resolution, misleading the observers. These kernels have following characteristics:

- they consist of turbulent magnetized plasma kept together by tension of tangled magnetic fields
- some of the magnetic flux exit/enter each kernel forming an analogy of sunspots (*k-spots*), at least three for a kernel (cf. Jakimiec, 2002)
- *k-spots* of different kernels are interlinked, forming arms, seen as classical loops if filled with plasma
- filling factor within kernels is close to unity, while in arms is very low
- transport is easy (classical) along the arms but very slow across kernels
- kernels at a given height tend to self-arrange into spiders (cf. Figure 5 right), a stable configuration resisting a slow increase of magnetic energy due to magnetic carpet activity
- spiders form a hierarchical, self-organized structure of several stages, forming thus magnetically closed large scale global configurations
- some of the kernels inside the closed configurations are linked to the solar wind magnetic fields
- these connections to solar wind provide necessary tension to constantly lift the kernels outwards of the Sun.

Constantly building stresses are being relaxed continuously through reconnections taking place within the kernels. Any of these reconnection leads to some field lines leaving one kernel and joining the other. In this process particle acceleration is taking place, so permanent presence of some non-thermal plasma component is expected. Some of these reconnections are followed by a catastrophic rearrangement, in case a vital magnetic topological link is "broken". This leads to chromospheric explosions, flares, CME-launches, and other dynamic phenomena observed.

The most of dynamical patterns of flare evolution studied tend us to believe that an "explosion" type of the energy release is rare in comparison with a disruption scenario. During flares, a widely discussed evaporation model of filling the corona with plasma has to be modified accordingly. The "evaporation" process is expected to operate efficiently, but from the kernel – not from the chromosphere-transition region. Evaporation of several subsequent kernels one-by-one may contribute to filling the main energy release volume, on exceptional cases reaching only a solar surface.

The presented outline of the atmospheric connectivity pattern may not be very easy to accommodate from a fist glance, but of its ability to explain multiple solar observations is very encouraging. We hope presented model will receive attention from solar physics community.

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References

Close, R.M., Parnell, C.E., Longcope, D.W., Priest, E. R.: 2004, *ApJ*, **612**, L81

Harrison, R. A.: 1997, *Solar Physics* **175**, 467 **30**, 577.

Jakimiec, J.: 2002, *Advances Space Research* **30**, 577.

Lu, E. T. and Hamilton, R. J.: 1991, *Astrophys. J.* **380**, L89.

Pres, P. and Kolomanski, S.: 2007, *Hvar Obs. Bull.* **this issue**

Sylwester, B. and Sylwester, J.: 1999, *Acta Astronomica* **49**, 85.

Sylwester, J. and Sylwester, B.: 2004, *Hvar Obs. Bull.* **1**, 71.

Sylwester, B. and Sylwester, J.: 2007, *Hvar Obs. Bull.* **this issue**

Schrijver, C.J, Derosa, M.L. Metcalf, T.R. Liu, Y., Mctiernan, J., Regnier, S., Valori, G., Wheatland, M.S. Wiegelmann T.: 2006 *Solar Physics*,**235**, p. 161.

Wang, T.: 2006, em Oscillations and Waves in Coronal Loops, `http://arxiv.org/abs/astro-ph/0612605v1`

Wang,T., Davina E.I., and Qiu, J.: 2007, *ApJ*, in press `http://arxiv.org/abs/astro-ph/0612566v1`