# CORONAL HEATING AND STRUCTURING

**Giovanni Peres**

Dip. di Scienze Fisiche ed Astronomiche, Sez. di Astronomia - Piazza del Parlamento 1 - 90134 Palermo - ITALY

ABSTRACT

This review discusses recent results on coronal heating and structuring related to observations made with coronal observatories of the last generation, e.g. SOHO, TRACE and Yohkoh. The topics include: inferring the three-dimensional spatial structure of the corona in slowly changing active regions, deriving the frequency of microflares vs. their total energy, using accurate models to interpret observations. Accurate models are required because the dynamics and energy balance of the coronal plasma involve several physical effects of comparable importance and some of them are non-linear. In this respect the paper presents the detailed modeling of a loop brightening, observed with TRACE at high temporal and spatial resolution, by means of a hydrodynamic model of magnetically confined coronal plasma. The model and the high quality observations allow us to infer the location and the distribution of the heating inside the loop, as well as its evolution.

Key words: corona, heating, MHD, coronal morphology.

## 1. INTRODUCTION

"How is the solar corona heated to million degrees?" and "How is the heating of the corona related to its structuring?" are fundamental questions of solar physics. The attempt to answer them has been central in a multitude of theoretical studies and among the fundamental tasks of many experimental programs. Albeit these questions have not been answered in a complete way, we now know much more than a few decades ago, thanks to spatially resolved observations, most recently those made with Yohkoh, SOHO, the Normal Incidence X-ray Telescope, the Transition Region And Coronal Explorer (TRACE) and, more in general, with instruments since Skylab. Spatially resolved observations have given us crucial insight into the coronal structure and have allowed us to focus better on the mechanisms underlying the heating and dynamics of the plasma.

A question related to the two above, since the magnetic field is volume filling in the corona and therefore is virtually all over the corona is: "Why some magnetic loops are bright (i.e. full with hot, emitting, plasma) and others are invisible?". Furthermore, since the plasma is optically thin, seeing well defined and isolated loops in any band and at any time means that the heating mechanism has to act always on a subset of loops. Therefore the loop heating has always to be somehow localized and the coronal filling factor is less than 1. Since thermal conduction is very effective in spreading heat along field lines but not across them, the transversal structure of loop systems must be related to the way in which the energy release mechanism is present across field lines (Litwin and Rosner, 1993).

Simultaneous observations of the corona typically show coronal arches visible in different X-ray and UV bands or lines are co-spatial but seldom - if ever - coincident. Also, with SOHO instruments and with TRACE we may see entire loops luminous in lines typical of the transition region, at variance with the paradigm that the thermal stratification inside a steady coronal loop ranges from chromospheric to coronal temperatures, but elsewhere in corona, in the same lines, we may observe bright low-lying plage-like structures without evidence of a loop structure. Probably they are the footpoints of the loops hotter and visible in X-rays. The large variety of structures we see in the corona may be due to the spatial and temporal variations of the heating or to different mechanisms by which the plasma is heated.

This review discusses some very recent work on coronal heating and structuring, in order to stimulate thoughts and arguments, rather than limiting the presentation to established results. Indeed some of the work I will discuss has just been submitted for publication and is subject to revision. On the other hand, extended reviews on heating mechanisms are in Narain and Ulmschneider (1990; 1996); more recent ideas can be found in Priest (1997; 1999) and references therein.

## 2. Yohkoh/SXT LOOPS VS. TRACE AND SOHO/EIT LOOPS

Yohkoh/SXT observations typically show loops whose width is not only well above the instrument resolution but also comparably broader than those observed by TRACE and by SOHO/EIT, especially in the 171 A and 195 A bands. At the same time Yohkoh certainly shows a dynamic corona, but apparently less variability in steady loops than TRACE (and probably also SOHO/EIT) does.

The following exercise (made with the help of F. Reale) may help to explain, at least partially, the causes of such a difference. I have considered seven isothermal loops, of the same length, with the same density but whose temperature ranges from 1 to 7 million degrees in steps of 1 million degrees. In Fig. 1 they are nested for ease of presentation and their temperature ranges from the coolest one, on the outside, to the hottest one, inside. This is a very coarse representation of a bundle of thin magnetic threads making a broader loop but it suffices for my point. By synthesizing the optically thin spectrum of each loop and folding it through the spectral response of each instrument we have simulated an observation of a multitemperature bundle of loops with Yohkoh/SXT (Tsuneta et al. 1991), TRACE (Tarbell et al., 1994), and SOHO/EIT (Delaboudinere et al., 1996).

The spectral and thermal responses in any band of Yohkoh/SXT extend over broad ranges, instead the spectral and thermal responses of each coronal band of TRACE and SOHO/EIT are much narrower. Fig. 1 also shows how Yohkoh would detect the same loop in the band selected with the Al.1 filter: most of the loops are visible, the 2 million degrees loop is barely visible and the 1 million degree one is practically invisible, if they all had the same emission measure.

The 171 A channel of SOHO/EIT or TRACE instead would only see the outer, 1 million degrees, loop and the 195 A of both instruments would see the outer, coldest two loops. A comparison of the three images would show different structures and those imaged by Yohkoh/SXT would be much broader.

Coming now to the dynamics of loops, if the heating - and therefore the temperature - in each loop changes even only slightly, Yohkoh would continue to detect the loop over a larger range of temperatures, because Yohkoh/SXT thermal response extends over a broad temperature range in each band. So the various loops will not appear to vary dramatically even if subject to small changes of temperature. Instead the same loop observed in one of the bands of SOHO/EIT or TRACE would appear to dim or brighten rapidly as the plasma temperature leaves or enters the narrow range of temperature sensitivity of the instrument. The higher angular resolution of TRACE, showing even finer components of the loops, may enhance the effect. In conclusion, Yohkoh/SXT may see a large fraction of a multi-temperature loop bundle while the other instruments only a small part. Also any small temperature variation may not make the loop change dramatically in Yohkoh images but may do it more easily in the images of the other two instruments.

J. Newmark during the meeting pointed out that the 284 A band of SOHO/EIT, which observes the hotter FeXV-line-emitting plasma, detects more diffuse loops than the other two coronal bands. On one hand the spectral response of this band seems to be slightly broader than that of the other two bands (Delaboudiniere et al., 1996), so observations in this band may detect plasma over a slightly broader temperature range. On the other hand one cannot exclude that Newmark's point just implies that, beyond the effect I just discussed, the diffuse nature of coronal loops is real but it occurs at temperatures well above 1 MK, more specifically above the temperature range to which the 171 A and 195 A bands are sensitive. This is a potentially important observational fact which may be worth exploring with multiband (or multi-line) observations at high angular resolution.

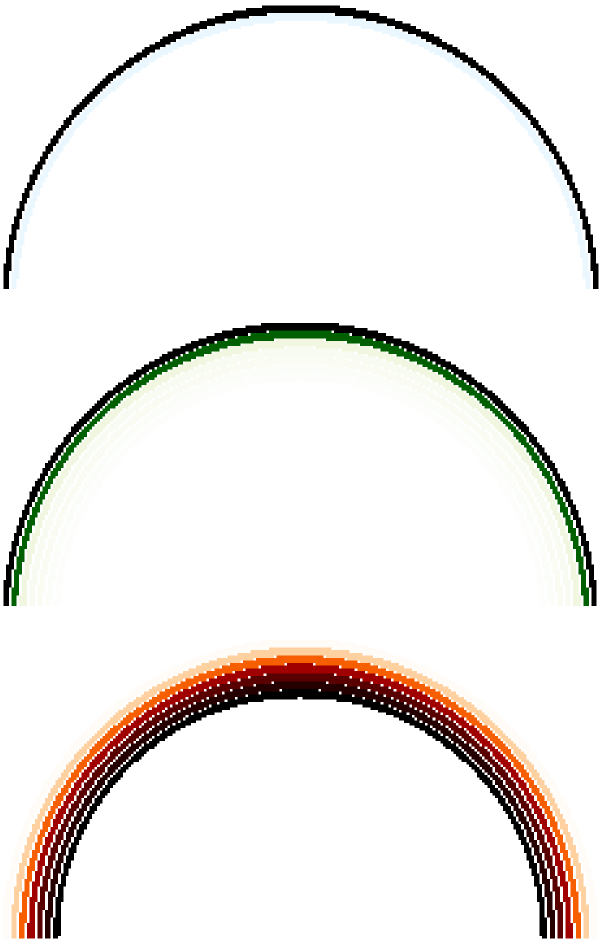

*Figure 1. Synthesized observations of a bundle of seven nested thin loops, each isothermal, and of temperatures ranging from 1 (outermost one) to 7 MK (innermost one) in steps of 1MK. Top panel, 171 A observations (either TRACE or SOHO/EIT), middle 195 A observation (TRACE or SOHO/EIT); bottom Yohkoh/SXT observation with the Al.1 filter.*

## 3. DERIVING THE 3-D STRUCTURE OF THE CORONA

Since the work of Vaiana, Krieger, and Timothy (1973) it was recognized that the corona is highly structured in loops whose plasma pressure and temperature may cover a large range. Present-day X-ray and XUV pictures show an amazing amount of details; however each line of sight may easily intersect many loops and, since the corona is optically thin, we cannot discriminate coaligned loops and their physical characteristics. Therefore, if one really wants to understand the structure of the corona, should derive the plasma density, temperature, velocity, etc. along each loop from the observations, as well as their evolution, in spite of the above problem. While this may be accomplished easily for isolated loops, it has not been possible to do it extensively and systematically for the whole corona or entre active regions.

Aschwanden et al. (1999a, 1999b) are pursuing the project to derive the 3-D conditions of the corona, limitedly to the active region 7986 observed with SOHO/EIT. Fig. 2 shows the active region; the relevant loops are put into evidence with a software filter enhancing structures and contrast. Since the magnetic structure of the active region does not change significantly in the three days during which it was observed repeatedly with SOHO/EIT, Aschwanden and collaborators claim to derive the loop 3D structure even if some individual loops may change luminosity, using dynamic stereoscopy, a method that they have devised. This method can be briefly explained as follows: considering an image taken during the middle day as a reference for the loops appearance and geometry, they methodically explore all the relative alignments and inclinations of the loops until those consistent with all the observations are found.

30 loops have thus been identified, isolated and studied in detail. Then the plasma distribution inside each loop has been studied with a loop model and after fitting the plasma distribution inside each of them Aschwanden et al. have derived scattering diagrams relating plasma pressure, loop length, magnetic field at the footpoints and volumetric heating. They also explored the applicability of a model of pulsed heating, i.e. a sort of microflares. The method is still undergoing improvements, the correlation is, in most cases, a rather scattered one and the strong pressure correlation they find may just reflect the fact that radiative losses are proportional to the square of plasma density.

Several questions are still open on this approach, concerning, for instance the uniqueness of the 3-D reconstruction and of the loop characteristics. The range of application is limited to regions which do not change significantly over a few days so it cannot be used systematically over the whole corona. On the other hand, it is one of the few projects - if not the only one - dedicated to derive the 3-D structure of the corona or of a large part of it. As such it can be important per se and also as an exploration which may show future paths and/or intrinsic limits of deriving the 3D structure of coronal plasma.

This study has been limited, so far, to two SOHO/EIT bands, a multi-band approach, i.e. using simultaneous observations in X-rays, UV etc. aimed at sampling plasma over a large range of temperatures would, on the other hand, allow to study the multi-temperature corona suggested by the presence of cold-lines loops.

## 4. MICROFLARES: SOME NEW DEVELOPMENTS

The microflares heating is a rather interesting and controversial issue, well beyond the context of the work by Aschwanden et al. Parker (1987, 1988) first proposed the terms "micro-" and "nano-flares. The underlying idea is that random photospheric motions drive the magnetic field lines footpoints, lead to the continuous braiding of the lines themselves and to generating a multitude of small magnetic tangential discontinuities (i.e. current sheets) in corona. The corona, in this scenario, is steadily heated by almost ubiquitous magnetic field reconnections occurring in these mini-current sheet simultaneously in several places of the corona. These small events are just a small version of flare events and hence the name micro-flares.

Peres et al. (1992), Kopp and Poletto (1993), Cargill et al. (1994), Cargill and Klimchuck (1997) developed hydrodynamic models of thermal microflares in loops.

Since the flares frequency vs. total energy follows very closely a power law of negative index, i.e. $F(E) = F_0 E^{-\alpha}$, the total rate of energy provided by the flares to the solar atmosphere is

$$P = \int_{E_m}^{E_M} F(E) E dE = F_0 \frac{{E_M}^{2-\alpha} - {E_m}^{2-\alpha}}{2 - \alpha} \tag{1}$$

Under the hypothesis that the microflares are just a small scale version of the flares and therefore the characteristics both of individual events and of the globality of the phenomenon can be derived from flares, considerable effort has been dedicated to extrapolate the low energy tails of the flare frequency distribution vs. energy to evaluate the possible energy contribution from microflares and to understand if it may explain entirely the coronal heating.

Extrapolating the known flares frequency distribution one gets a rate of energy deposition insufficient to heat the corona "steadily". On the other hand the microflare model requires that the steady heating, and most of the energy budget, comes from small flaring events. A negative index, in modulus larger than 2, is required if the energy budget has to be dominated by small events. Inferring the flare total energy requires deriving the energy budget through a model, some authors therefore prefer to report the maximum flux during the event, a more directly observable quantity, although it is less directly related to the event energy budget.

Several observations have tried to shed light on microflares: hard X-ray observations of small nonthermal X-ray events whose energy is distributed according to a power law by Lin et al (1984); Dennis (1985) reports on a large set of flare events observed with the SMM/HXRBS and gives a power law index for peak hard X-ray flux of -1.8 and for total energy of -1.53. Similarly Crosby, Aschwanden and Dennis (1993) analyze systematically a large set of events; they give -1.73 and -1.53. It is worth noting that hard X-ray observations provide evidence of non-thermal electrons and there may not be a one-to one correspondence of electrons non-thermal energy with the plasma heating; it is worth using, therefore, also data taken in other bands and which sample more directly the thermal phase of the flares and microflares, such as soft X-rays and XUV.

Soft X-ray peak fluxes of regular flares have a index between -1.84 (Hudson, Peterson and Schwarz 1969) and 1.75 (Drake 1971). More recently, Shimizu

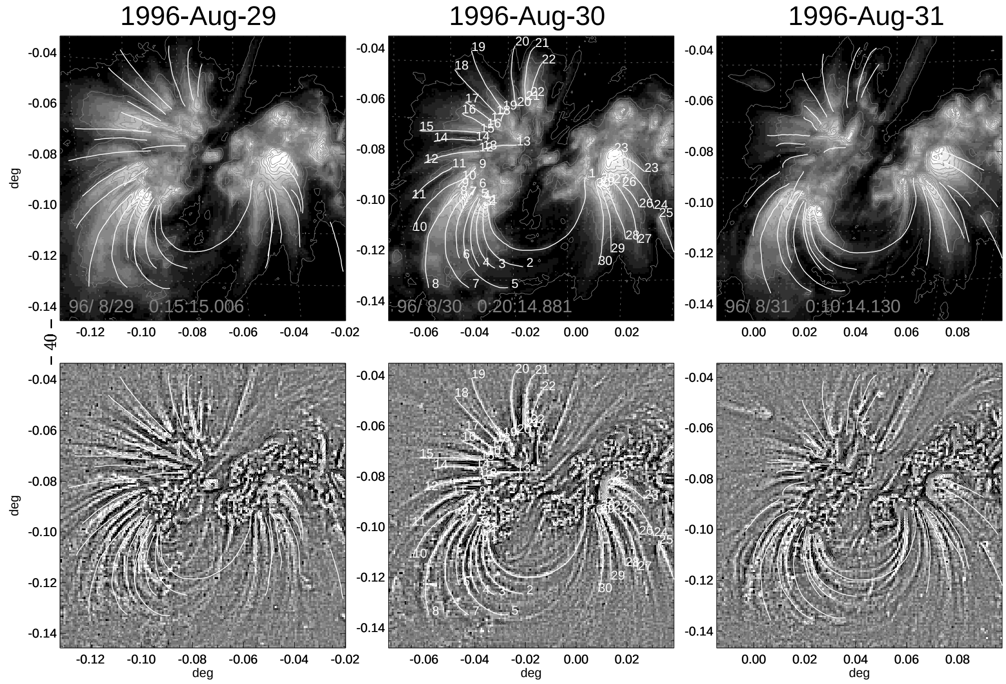


*Figure 2. This figure shows the AR 7986, in three consecutive days during which the data used by Aschwanden et al. (1999a) were taken. The upper panels are the SOHO/EIT data, in the 171 A band, with solar coordinates and additional information. The lower ones show the same data after a software filtering to enhance the contrast. The white lines mark the projection of 35 stereoscopically reconstructed loop segments (from Aschwanden et al. 1999a).*

(1995) has studied extensively the very small brightenings observed by Yohkoh/SXT; he finds a power law distribution with an index between 1.5 and 1.6 for total flare thermal energy input larger than $10^{27}$ ergs, and the total energy given by these events is at most 20% of what is needed in active regions. More recent results have been produced by Shimizu and Tsuneta (1997). Therefore, at present there is no evidence from hard and soft X-ray observations that microflares provide enough energy to heat the "steady" corona and, more specifically, the active regions, if they follow the same frequency distribution of large flares.

Recent XUV observations may yield additional, important, observations, especially on the quiet corona. Benz and Krucker have dedicated significant effort to small brightenings observed in X-rays and XUV and tried to connect them to microflares. More specifically, Krucker et al. (1997a) have studied soft X-ray microflares in the quiet Sun network, and found that they are mostly due to an increase of emission measure (see also Krucker et al., 1997b) rather than to changes of temperature and they claim that these events may be due to evaporation. Krucker and Benz (1998) have studied the energy distribution of brightenings using SOHO/EIT observations in the 171 A and in the 195 A; they followed the evolution of emission measure in all the pixels of the image. Almost each pixel seems to fluctuate significantly. They have selected the local peaks as brightenings and, on the basis of their previous work, they have assumed that each brightening is mostly due to the EM increase due to evaporation caused by a heating event. Consequentely, they have derived the energy in each event through the formula $E = 3K_BT\sqrt{\Delta MAqh}$ where E is the event total energy, $K_B$ is the Boltzmann constant, $T$ is the plasma temperature, $\Delta M$ the change of emission measure, h the depth along the line of sight and q the filling factor of the evaporated material. Note that the energy they derive is a lower limit of the event; furthermore the model they use to derive the energy is a rather simplified one. They have made a histogram of the events frequency vs. their energy, and found that they distribute, in the range between $8 \times 10^{24}$ and $6 \times 10^{26}$ ergs, according to a power law with index between -2.3 and -2.6 (cf. Fig. 3). They have examined the distributions obtained considering all the events with an amplitude, at least 3, 4 and 5 $\sigma$ of the background fluctuations, respectively, as well as those corresponding to events encompassing, at least 1, 2 and 3 pixels; for all of them they find the same power law index. The set of $3\sigma$ events yield $7.1 \times 10^4$ erg cm$^{-2}$ s$^{-1}$ i.e. already 16% of the total enegy required for the quiet corona. If the power law continues unchanged to $3 \times 10^{23}$ ergs there is enough energy to heat the quiet corona.

Parnell and Jupp (1999) propose a slightly modified approach of the same kind. They look for variability in the TRACE data - which have a higher spatial and temporal resolution - making the same assumptions as Krucker and Benz (1998) for the events selections and for deriving their energy. They adopt a slightly more sophisticated statistical approach not grouping their events in energy bins so as to maintain the whole statistical information contained in their distribution. They also use an "underreporting" function

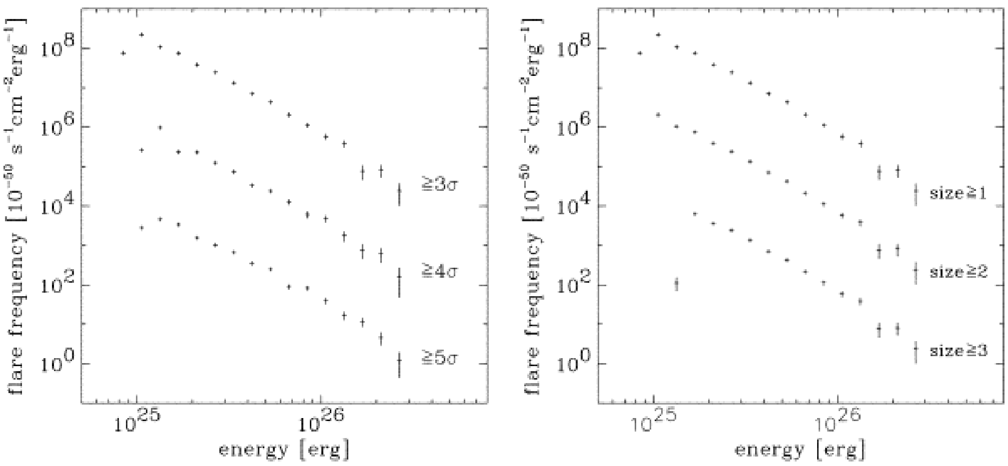


*Figure 3. Frequency of small brightenings, detected with SOHO/EIT in the 171 A and 195 A bands, vs. the event energy. Left panel: distributions of events with an amplitude of, at least, 3, 4, and 5 times $\sigma$, i.e. the amplitude of background fluctuations. Right panel: distributions of events involving, at least, 1, 2, and 3 contiguous pixels. From Krucker and Benz (1998).*

to consider the coarse time resolution and that there is a finite probability of missing the highest and lowest values of brightness in each pixel; therefore the variations detected are smaller than real. They find that the events frequency distribution vs. energy in the range $10^{24} - 10^{26}$ ergs is a power law with an index -2.4 – -2.6. The events they have observed provide $5.2 \times 10^4$ erg cm$^{-2}$ s$^{-1}$ and, if the power law remains unchanged down to $5 \times 10^{22}$ erg there would be $3 \times 10^5$ erg cm$^{-2}$ s$^{-1}$ i.e. enough heating for the quiet corona.

The above two studies are quite interesting, but they should be also be compared with other studies on similar SOHO/EIT studies presented by Berghmans et al. (this pubblication) and by Clette (this pubblication) which find a significantly smaller absolute value of the power law index. One of the main difference lies in the criteria for event selection and, in particular, on the way to consider events occurring in nearby pixels as independent or related.

More in general, any analysis using the emission measure derived from narrow band instruments, such as TRACE and SOHO/EIT may be seriously affected by the non uniqueness of the temperature determination - and consequently of the emission measure determination - due to the several temperature values yielding the same flux ratio. The common approach to tackle this feature by restricting to a narrow temperature range, i.e. where the temperature vs. filter-ratio relationship is single-valued and the dominant spectral lines form, may explain the small temperature ranges that the above authors find in their events.

## 5. DETAILED MODELS ARE IMPORTANT FOR DIAGNOSTICS

In order to derive the energy of each microflare from observations, the studies discussed in the previous section needed a model of the event. Analogously, Aschwanden et al. (1998, 1999) needed a model to infer the energy budget of the loops identified. More in general, a model of the structures and the events is fundamental to understand and diagnose them with observations and, in particular, to infer the heating.

The connection between the heat spatial distribution, its timing and observations is not obvious! For instance, heating may occur where there is little plasma to emit, heat is then conducted away along field lines and another region, connected by magnetic field lines to the primary heating place, but far from it, is the first to brighten. Therefore the assumption that the place where a brightening is observed is the same of the heat release, may be incorrect. Below, when discussing the work by Reale et al. (1999a, 1999b), the presentation will show how the connection between observed brightenings and heating may be non-obvious.

The fact is that, even just a hydrodynamic/thermodynamic model of the confined plasma, shows that the connection of the heating with plasma conditions (temperature, density and velocity) and, finally, with observations involves several physical effects (conduction, viscosity, radiative losses, etc.), all at work simultaneously and many strongly non-linear. The point is that there is a very complex relation linking what we observe with the place and time over which the heating is deposited. Therefore an accurate model is needed to infer reliably such a relation. This aspect was recognized at least since the analysis of Skylab observations. Past examples of modeling to infer the plasma features and to constrain the heating include Pallavicini et al. (1981), based on Skylab data, Peres et al. (1987), based on SMM data, and Reale et al. (1988), dedicated to a flare on Alpha Cen.

More recently Priest et al. (1998) has studied a large arcade of loops observed with Yohkoh/SXT, showing through accurate modeling, that the heating is uniformly distributed along the field lines in the coronal loop. Walsh (this issue) has revisited this study showing that a more correct evaluation of the overall energy budget should have included the transition region. However one of the aspects of the work by Priest et al. (1998) is still valid even after the analysis by Walsh, namely that the temperature profile can constrain the heating distribution along the loop and that the heating is quite uniform. This remains true independently of the inclusion of the transition region, since it depends on the local temperature profile.

On the other hand Antiochos et al. (1999) and more recently Betta et al. (1999) have found that it is possible to generate a siphon flow inside a coronal loop, with a temperature inversion and a density condensation at the apex, i.e. something similar to a quiescent filament, by concentrating the heating at the loop base. It appears, therefore, that heating may be very differently distributed along the field lines depending on the kind of structure or, conversely, different ways of depositing heat can give rise to a large variety of morphologies.

## 6. ACCURATE MODELING CAN GIVE INSIGHT ON THE HEATING

In the perspective of the previous section, the rest of this paper will be dedicated to show how the application of a detailed hydrodynamic/thermodynamic code to model a sequence of observations of high angular and temporal resolution obtained by TRACE may yield crucial constraints on the location and timing of the heating responsible of a loop brightening (Reale et al., 1999a, 1999b). The TRACE images, relative to AR 8253, were taken on June 26, 1998 with a cadence of one frame every 30 seconds for a few hours, only in the 171 A band, and the pixel resolution is half an arcsecond. The sequence imaged a region very close to the solar disk center. A loop brightens distinctly and its evolution lasts more than two hours; the loop geometry does not change during the event. The loop footpoints are the first to brighten, then bright fronts arise from them, first from the northern footpoint, $\approx$ 10 min. after the initial brightening and further 7 min. later from the southern footpoint. The front propagate at an apparent speed of 100 Km/s. At all times the brightness distribution along the loop remains strongly asymmetric, with the northern footpoint and leg brighter than the southern ones.

Reale et al. inferred from the image analysis that the loop is almost semicircular with a footpoints distance of $\approx 10^{10}$ cm and an apparently equal distance between the center of the footpoints and the apex. The loop appears inclined on the solar surface by 60 degrees. Being almost at the solar disk center, if it were vertical a de-projection would yield that it is two to three times longer than the footpoints distance: a rather stretched magnetic field configuration. Therefore Reale et al. found an almost semi-circular configuration much more plausible. The loop is not horizontal (or almost horizontal) on the Sun's surface otherwise the loop would fill much more rapidly during its evolution.

Since the loop is invisible at the beginning, the authors assumed that the plasma is initially at a temperature of $5 \times 10^4$ K and at a pressure of 0.01 dyne cm$^{-2}$, i.e. it is at rather low temperature, pressure and density. In order to help in comparing model results with observations, they have taken the surface brightness along the loop and mapped it back onto a semicircular loop.

Reale et al., have used the Palermo-Harvard hydrodynamic code (Peres et al., 1982; Betta et al. 1997); it solves numerically the 1-D differential equations of mass, momentum, and energy conservation along the field line coordinates in a non-symmetric coronal loop; typically (but not necessarily) a semi-circular geometry is assumed, the cross section is constant, both these geometrical assumptions are appropriate for the loop observed. The heating term is formulated as a separable function of position along the loop and time. The spatial distribution is gaussian and different locations and widths along the loop can be (and have been) chosen; different functional forms for the time evolutions have also been explored.

The way in which the observation has been fitted with the model can be summarized as follows: first, the geometry of the loop has been studied and defined and, then, the initial conditions of the plasma inside the coronal loops are inferred. After setting up the initial conditions, the intensity, spatial distribution and evolution of the heating are prescribed and the plasma evolution is then simulated. The emission in the band, or line, of the observation is then synthesized from the evolving plasma density and temperature distribution along the loop, taking into account also the characteristics of the instrument. Finally the evolution of the emission is compared with observations. From the comparison it is then possible decide if and how to adjust the characteristics of the heating so as to fit better the observations. It is worth noting that the approach is to reproduce the observation at best, rather than a statistical fitting.

The geometry does not change significantly during the entire evolution; at the beginning, albeit many loop subfilaments or threads appear to brighten simultaneously, they all behave very coherently for the entire rising phase (approximately 3000 sec); later the several threads seem to behave differently. Reale et al. have fitted just the rising phase, to which the model can be correctly applied.

When interpreting the results one has to take into account that the observation have a relatively narrow thermal response and therefore plasma is visible mostly in a narrow temperature range unless it has a high emission measure in a nearby temperature range. A crucial figure to which Reale et al. have paid attention is the contrast between footpoints and loop apex; also the relative timing of the brightenings at the apex and at the footpoints can be very useful to diagnose the heating characteristics.

The first attempt, since the first brightening occurs at a footpoint, has been to concentrate the heating at one footpoint. The results are in Fig. 5. The interesting fact is that, in the simulated evolution, the opposite footpoint brightens first because there the plasma is compressed and the emission measure increases. This is a clear example that a straightforward (and perhaps naive) interpretation of observations on the

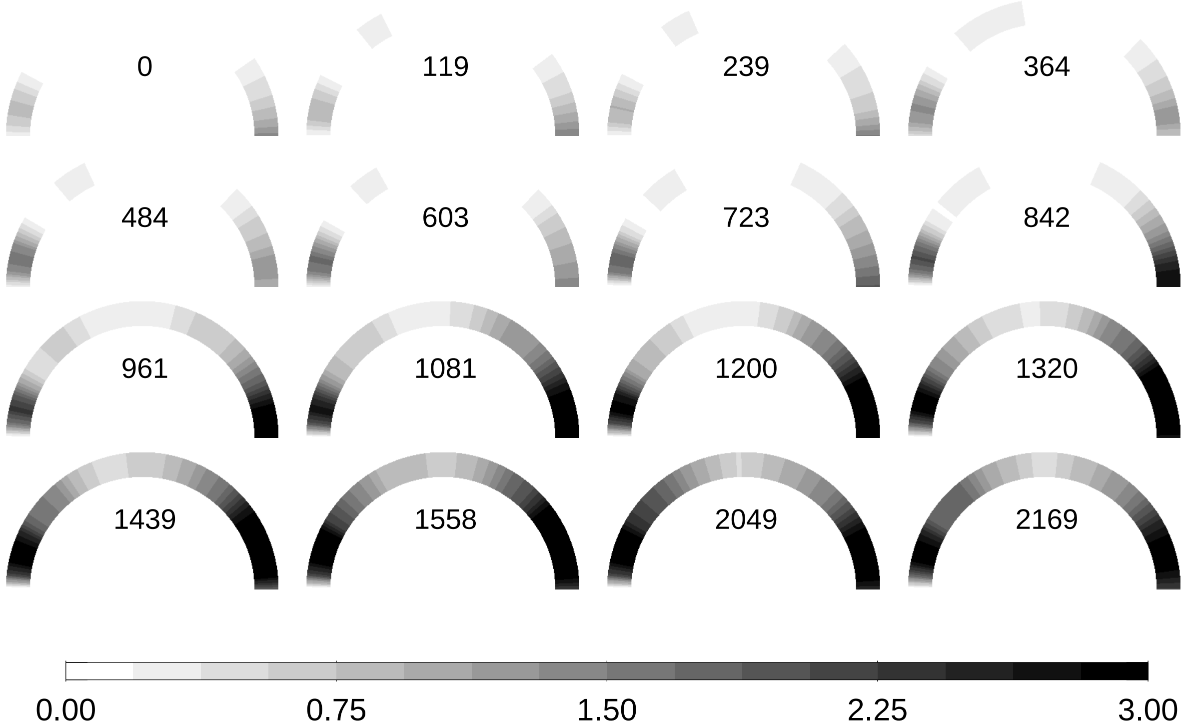


*Figure 4. Evolution of the loop brightening observed with TRACE in the 171 A band (see text for additional details). The loop surface brightness has been measured along the loop and mapped onto a semicircular loop of total length* $10^{10}$ *cm here shown. The numbers marking each loop image are second reckoned since the start time of the brightening (13:32 UT), i.e. 1875 seconds since the start of the observing sequence (adapted from Reale et al., 1999b).*

location of the heating can be wrong. Equally important in the context of simulating the observation, this simulation does not work because the two footpoints and the two halves of the loop brighten alternatively; instead observations show that the two footpoints brighten with only a slight time difference.

On the other hand, the footpoints would brighten simultaneously if the heating is located exactly at the loop apex. The heating cannot be, therefore, at the footpoints or at the apex. Judging from the observed timing and contrast of footpoint brightenings, Reale et al. propose that the heating has to be at one third of the loop's length, reckoned from one footpoint, and on the opposite side of the footpoints which brightens first. The relevant simulation works well, much better than the previous one, and the evolution of the brightness in the 171 A band, along the loop, is quite similar to the observed one.

The heating in all the simulations discussed so far is turned on suddenly and it remains constant. However, at advanced time of the evolution, the observed brightness distribution is flatter along the loop, than the one Reale et al. obtain. In order to improve on the fitting, they tried a heating higher at the beginning and decaying exponentially afterwards, indeed obtaining a smoother brightness profile at later times (cf. Fig. 6). This simulation is definitely the best, among those tried by Reale et al., in reproducing the spatial and temporal distribution of the emission along the loop.

There is a bright structure in the TRACE images in the place where the heating should be located, according to the simulations. It shows small substructures which evolve continuously. It can easily be a coronal structure coaligned by chance and it may have nothing to do with the heating; it may also be that we are observing directly the site where the energy release is taking place. This information may be crucial for people who does theory of coronal heating for putting constraints to their theory.

## 7. SUMMARY

This presentation has addressed some of the most recent and significant developments about coronal heating and structuring, based on data mostly obtained with SOHO but also with other coronal observatories. It is evident that the heating of the magnetized coronal plasma determines the structure of the emitting corona; most likely also the magnetic structuring influences the heat release mechanisms.

Understanding the complete three-dimensional structure of active regions (not to mention of the whole corona) is a quite difficult task. One of the most complete attempt, by Aschwanden et al. (1999a), is trying to ascertain the structure of magnetic field, of plasma temperature and density and, ultimately, of the loops heating. At the same time the first studies are encouraging but evidently require significant improvements and are, necessarily, limited at present

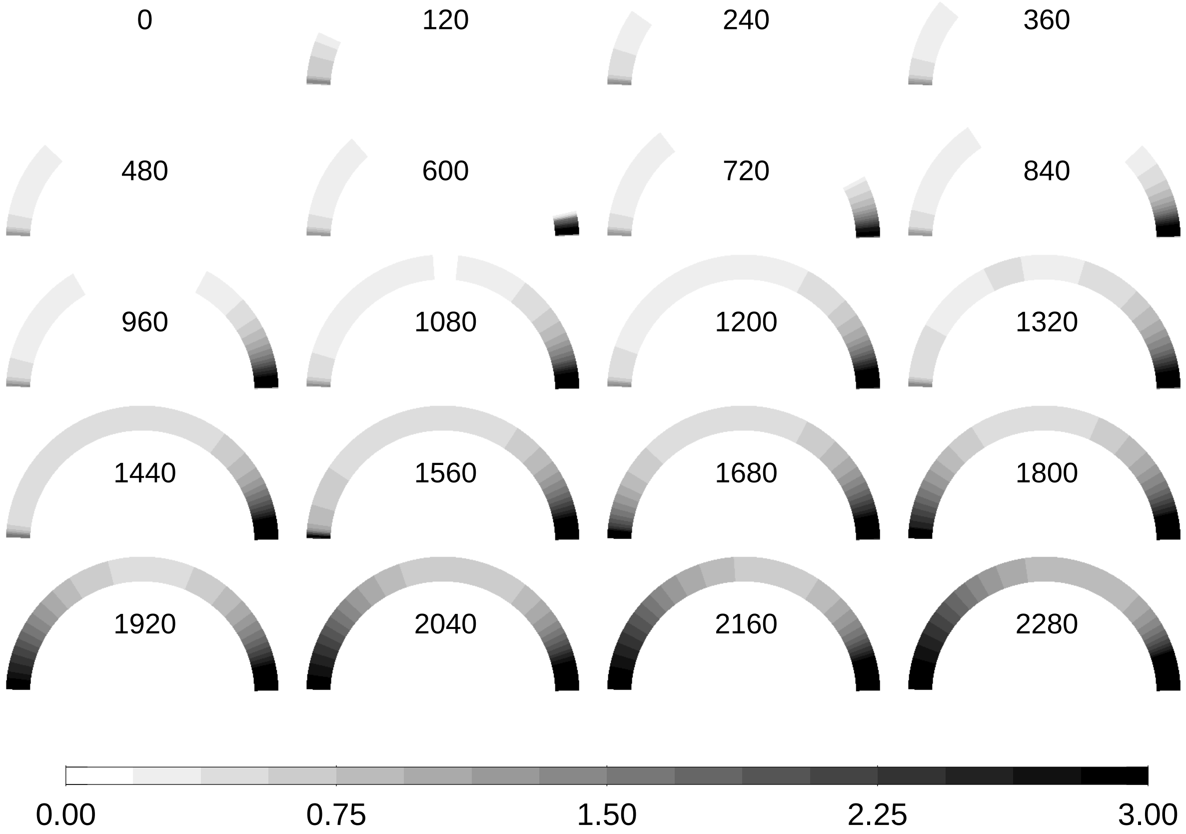


*Figure 5. Results of the hydrodynamic model based on footpoint heating: surface brightness, in the 171 A band, along the loop at the time, in seconds, since the beginning of the heating shown by each loop image. The left footpoint is heated with a gaussian spatial distribution centered at* $3 \times 10^8$ *cm from the base, and with* $\sigma = 5 \times 10^7$ *cm, the maximum heat intensity is* $10^{-2}$ *erg* $s^{-1}$ *cm*$^{-3}$ *and it lasts continuously for 3000 s (from Reale et al., 1999b).*

time to regions well observed over limited time and whose magnetic structure changes little.

Also the filamentary structure of the coronal loops observed by SOHO/EIT and TRACE 171 A and 195 A bands, vs. the more diffused structure observed at higher temperatures in the 284 A band of the same instrument or by Yohkoh/SXT may tell us something fundamental on the way heating is released across the magnetic field lines.

The microflare heating model is finding new observational constraints in the observations made with SOHO/EIT and TRACE. Probably the most controversial part lies in the way to interpret the spatially resolved observations but the implications can be far reaching since the approach by Kruecker and Benz (1998) and by Parnell and Jupp (1999) leads to a event frequency distribution which may provide enough power to heat the quiet corona. The other approach, by Berghmans et al. (this pubblication) and by Clette (this pubblication), analysing similar events, instead, does not.

In any case it appears that using a model, as accurate as possible, of the phenomenon is of fundamental importance to interpret observations correctly. A few examples show the level of insight possible when an accurate model is coupled to high quality observations. Probably the best example of this class of very advanced applications is the work by Reale et al. (1999b) who have used an accurate hydrodynamic and thermodynamic model of coronal loop to interpret a sequence of TRACE observations of high time cadence and spatial resolution. The quality of the observations allows Reale et al. to constrain at an unprecedented level the model and to derive the spatial distribution and the evolution of the coronal heating.

## ACKNOWLEDGMENTS

I acknowledge stimulating discussions with F. Reale and help by S. Orlando. This work was partially supported by Agenzia Spaziale Italiana and by M.U.R.S.T.

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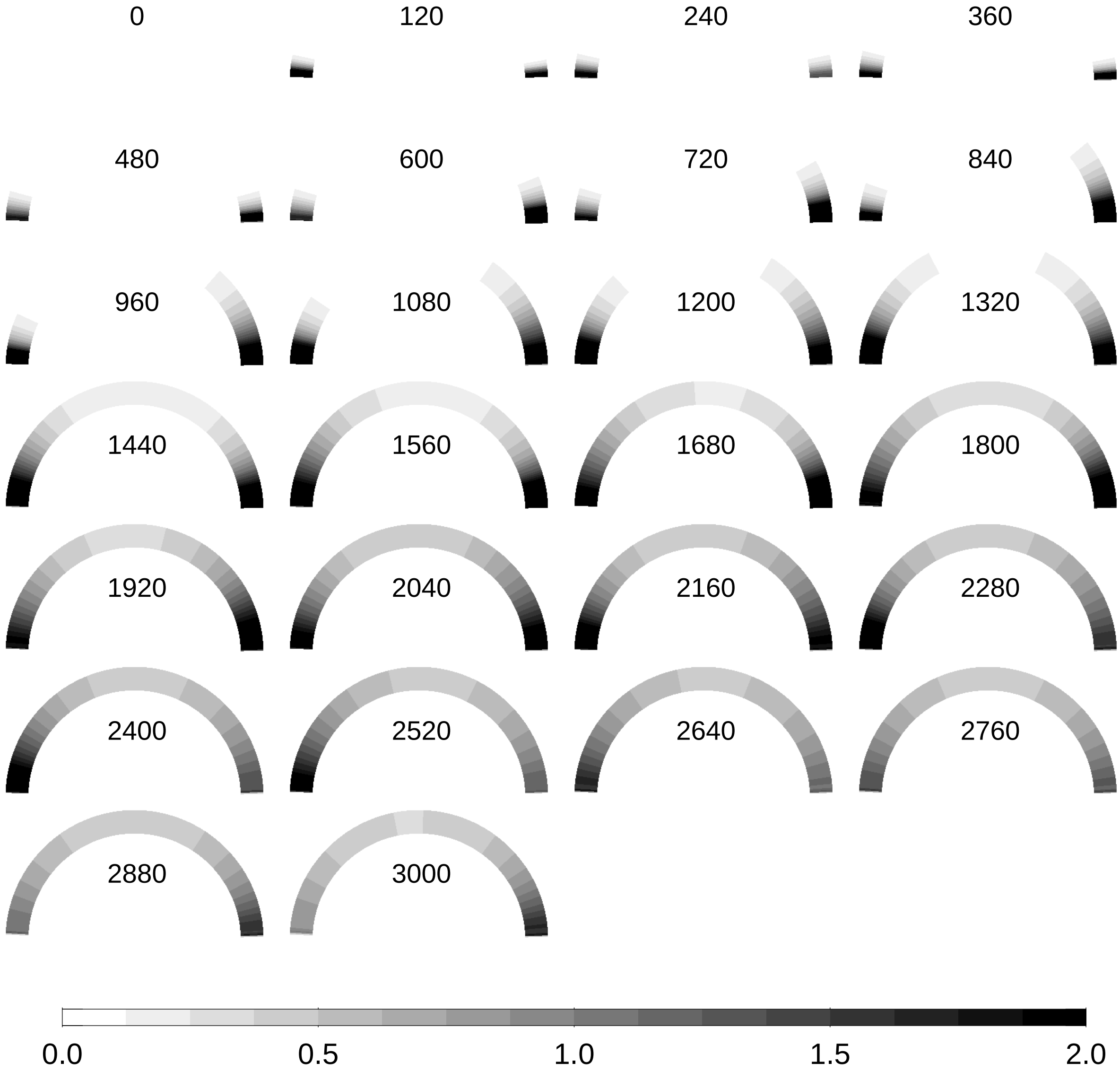


*Figure 6. Analogously to Fig. 5. The gaussian distribution is centered at* $3 \times 10^9$ *cm reckoned from the left footpoint, with* $\sigma = 5 \times 10^8$ *cm, maximum intensity* $4 \times 10^{-3}$ *erg* $s^{-1}$ *cm*$^{-3}$*, constant for the first 100 s and then exponentially decaying with an e-folding time of 300 s (from Reale et al., 1999b).*


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