CHROMOSPHERIC AND TRANSITION-REGION HEATING PHENOMENA:
COORDINATED GBO AND SOHO OBSERVATIONS

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Abstract

Large-scale (flares) as well as small-scale (chromospheric and TR brightenings, sub-flares, etc.) heating processes are supposed to have a common origin in the magnetic-loop energy release on various spatial and temporal scales. A chromospheric and TR response to the energy transport from the corona provides us with wealth of informations concerning the energetics and dynamics of these heating processes, but the energy release can take place also directly in these or even lower layers. From the theoretical side, such processes are being studied using the radiation-hydrodynamical modelling of plasma loops and NLTE spectral diagnostics of the chromospheric and TR plasmas. Here we suggest the coordinated observations of such events in both UV and optical lines and continua, using SOHO instruments (SUMER, CDS) and the automatic Multichannel Flare Spectrograph (MFS) operating at Ondřejov Observatory. Especially the plasma dynamics (flows) in the chromosphere and TR can be studied from spectral line profiles - for some flare-like phenomena we present here new computations of asymmetrical hydrogen Lyman and Balmer line profiles. Such asymmetries represent the basic diagnostics of the plasma flows observed simultaneously with SUMER and MFS instruments.

1. INTRODUCTION

Spectral observations of solar flares and flare-like phenomena (FLP) have a long tradition in solar physics and wealth of data has been obtained and analysed. However, most of individual analyses have been confined to rather restricted spectral bands, and many of them even to one or two spectral lines. In optical region, such a favorite line is the hydrogen Hα line. In the case of flares and flare-like brightenings, UV or EUV data came mostly from Skylab, UVSP/SMM and HRTS, some also from OSO satellites. Ground-based observations (GBO) of flare and FLP spectra, made simultaneously in several optical lines, are not very common now but some recent multiline studies have revealed new aspects of the flare dynamics and energetics (Falchi et al., 1992; Heinzel et al., 1994). In fact, there exist no systematic studies of these energetic processes carried out simultaneously in UV (or EUV) and broader optical spectral passbands. Even such a trivial problem as the relation between hydrogen Hα and Lo lines, representing the chromospheric and low TR conditions, was not systematically studied due to the lack of simultaneous data.

The problems which can be addressed using such multiline and multicontinuum spectral data, having sufficient spatial (≥ 1 arcsec), temporal (around or less than 1 sec) and spectral (a few km s⁻¹) resolution, are numerous and we briefly summarize them as follows:

- Heating mechanisms in TR, chromosphere and photosphere (conductive fronts, energy transport due to accelerated particles, reconnection);
- Recognition of true site of the energy release: is it mostly in the corona or directly inside the TR or even lower?
- Mass flows in heated loops: is it outflow, downflow or expansion? Velocity gradients can be derived using different TR and chromospheric lines;
- Depth-dependent atmospheric structure, MHD-equilibria, departures from hydrostatic atmospheres at the base of the loops, inhomogeneities;
- Energy budget: radiation losses are to be derived from as many as possible lines and continua, using time-dependent ionization structure.

To solve these problems, we need basically three tools:
- Simultaneous EUV and optical (possibly also IR) observations which are not yet available in such a complex manner;
- Multispecies, multifrequency (several lines and continua) spectral diagnostics methods based on modern NLTE (also time-dependent) approaches;
- Radiation-hydrodynamical simulations of heating processes and dynamics in loops which are supposed to be the basic MHD structures where flares and/or FLP do occur.

In this contribution, we suggest a joint observational and theoretical project aimed at understanding the chromospheric and TR heating and energy transport phenomena.


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2. COORDINATED SOHO AND GBO OBSERVATIONS

Although SOHO is not a flare mission like SMM, we believe that the abovementioned questions will be tackled since they involve much broader class of events which we call FLP. For UV (or EUV) spectroscopy, SOHO will operate two instruments of interest: SUMER and CDS. The wavelength range of these spectrometers is:

50 - 160 nm for SUMER
15.5 - 78.7 nm for CDS.

The spatial resolution is 1-2 arcsec for both instruments and the temporal one down to 1 sec (for SUMER, exposure times may be as low as 20 ms in specific regimes). For a detailed description of both SUMER and CDS see so-called red and blue book, respectively (also in ESA SP-348).

A prototype of a complementary optical spectrograph, which is ready to operate simultaneously with SOHO (full-day operation, restricted only by weather conditions) is described below. In its CCD multiline video mode, this instrument can follow the selected target fully automatically, with spatial and temporal resolution comparable to SUMER or CDS.

2.1 Multichannel Flare Spectrograph (MFS)

The automatic Ondřejov Multichannel Flare Spectrograph (MFS) is a medium size GBO facility which can be operatively used for obtaining solar optical spectra in selected bands according to Table 1. The feeding telescope is a horizontal one with the main objective mirror 230mm/1350cm. The telescope and spectrograph optical systems can be seen in Figure 1.

The grating 90 x 100 mm with 600 lines/mm is blazed into the second right order. The main advantage of this instrument is that the spectra in the spectral cameras No. 1 - 5 are recorded simultaneously with linear dispersion 1 Å/mm. In addition to these 5 spectra obtained in the second right order we take additional spectra in the third left diffraction order with linear dispersion 0.60 Å/mm in the 6th camera and 0.76 Å/mm in the 7th camera (see Table 1).

The spectra are registered on a 36 mm film, the length of the film strips can be chosen individually in each spectral region. Due to the large apertures, short exposure times of about 0.1 sec for solar disk flares and a few seconds for limb effects can be used. Exposure times in the third diffraction order are about a factor 5 longer.

A reflecting planparallel plate 50 x 50 x 1 mm made from near UV transmitting optical glass with a 53 μm thin and 50 mm long transparent slit is used instead of a classical slit and it feeds the slit-jaw system composed of an imaging lens objective and Hα Day-Star filter with 0.5 Å passband. Images are registered by a CCD video camera. A slight inclination of the Hα filter enables us to see and register the slit-jaw picture in near or more distant wings of the Hα line profile. For further details concerning MFS see Kotrč et al. (1992).

As the need of a high temporal resolution in solar flare spectral data became more urgent, the MFS was further improved. A new control system of the spectrograph operation based on PC was implemented and it is now being tested. This system operates semiautomatically, controls the exposures in all cameras, provides an automatic scanning regime, registers the exact time of observation and stores all the necessary informations related to the observation. We work also on a possibility to select the best time for observation finding automatically the best seeing conditions and pushing the spectrograph trigger. The MFS computer receives the DCF time signal which is registered in the video cassette recorder (VCR). Thus we are able to exactly compare our spectra and video pictures to data obtained from space-born telescopes like YOHKOH and SOHO. Additional CCD cameras (in Figure 1 and Table 2 denoted as camera No. 9) working in video mode have been placed into a few selected spectral lines like Hα, NaI-D, CaII-K, etc. This set can be modified. Therefore we can simultaneously obtain spectra spanning various chromospheric heights with temporal resolution as high as 40 ms. The synchronized signals from video cameras (both slit-jaw and spectrum) are electronically composed and stored at VCR.

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<th>Table 1: MFS film cameras</th>
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Figure 1: Optical scheme of the Multichannel Flare Spectrograph (MFS). Feeding horizontal telescope is in the right bottom corner. For the parameters of individual cameras see Tables 1 and 2.

Figure 2: An example of CCD video image synthesis. Left: slit-jaw Hα image with vertical spectrograph slit. Right: corresponding Hα spectrum. Active-region chromospheric brightening (FLP) was detected at 6:59:20 UT on July 3, 1994.
The spectrograph control system can operate in two modes: ordinary spectrograph with a fixed slit position and an imaging spectrograph with a scanning slit.

2.2 Example of a CCD imaging

In Figure 2 we show an example of video-signal synthesis from two CCD video cameras: Hα slit-jaw image and Hα spectrum. In slit-jaw image, the vertical spectrograph slit is clearly visible. Two perpendicular hairs are used to define the spatial position in the spectra. CCD works at video rate 25 frames per second and the number of an individual frame is indicated at the bottom (16 in the present case). The composite image shows the chromospheric brightening typical for FLF. Both slit-jaw image and the spectrum have been digitized from the video record by using 8-bit frame grabber connected to PC.

3. HEATING PROCESSES AND RADIATION-HYDRODYNAMICAL SIMULATIONS

We think that such simultaneous GBO and SOHO observations will provide us with an important information concerning the heating processes of chromospheric as well as transition region layers and thus help us to distinguish among the following theoretical models. Namely, besides the heating of these layers due to the electron, proton or neutral beam bombardment from coronal energy release sources, there are heating processes which can be generated directly in chromospheric or TR layers. While in the first case the processes in deep layers can be considered only as a response to coronal heating and acceleration, in the second one the active processes are located in deeper layers. Now, let us present arguments which are used for the explanation of different locations of the energy release and heating processes in the solar atmosphere.

The concept of the coronal acceleration and subsequent chromospheric heating is similar to that in solar flares (Somov, 1992). It is assumed that particles are heated and accelerated in coronal parts of the magnetic loops, they propagate along the magnetic field lines down to the chromosphere, which is then heated (MacNeice et al., 1984; Mariska et al., 1989; Karlický, 1990). For higher energy fluxes the return-current effect becomes important, which causes a strong heating of the transition region, mainly for relatively cool coronal parts of the loops (Karlický and Hénoux, 1992 - see Figure 3). The dm-radio bursts are used as main arguments in favour of the coronal position of energy release. But, there are certain problems with this concept, e.g. with the transport of intense particle beams from the corona to the chromosphere (Brown et al., 1990). Furthermore, there

Figure 3: Velocity, temperature and density of the solar atmosphere heated by a beam pulse. Top: plasma velocity profiles at 1.47 sec (dashed) and at 4.44 sec (dotted). Upward motions have positive velocities. Middle: initial temperature profile (full line) and temperature profiles at 1.47 sec (dashed) and 4.44 sec (dotted). Bottom: initial density profile (full line) and density profiles at 1.47 and 4.44 sec.
are observations that flare soft X-ray emission, indicating a heating, starts at the footpoints of magnetic loops (Hudson et al., 1994). It is necessary to emphasize that from the theoretical point of view the transition region is very interesting as the place of energy release. Namely, at this region the electric currents can be concentrated in the converging magnetic field, and it is known from laboratory and numerical experiments (Chanteur, 1987) that the double layers can be formed on the contact layers between hot and cool plasmas. The presence of sufficiently dense electric currents and corresponding ohmic electric fields generated due to classical resistivity can additionally accelerate electrons, which thus can penetrate deeper and heat denser layers (Karlický, 1994 - see Figure 4).

Furthermore, going to even cooler chromospheric layers, the classical resistivity is increasing. In the case of the existence of sufficiently high electric currents at these layers, the efficient reconnection of magnetic field lines is then expected even in the temperature minimum region as recently suggested by Litvinenko and Somov (1994).

It is clear that different locations of the heating in the solar atmosphere will generate different plasma flow patterns in chromospheric and transition region layers, leading to various asymmetries of optical and UV spectral lines (see next section), as well as different intensities and temporal behaviour of these lines. But a complexity of these data requires a comparison with radiation-hydrodynamical models. In this direction we started with a relatively simple 1-D hybrid hydrodynamic model of electron beam bombardment in magnetic loops (Karlický, 1990; Heinzel and Karlický, 1992), and now we are constructing more sophisticated models including return-current effects, external electric fields and consistent treatment of time-dependent radiation processes.

4. DYNAMIC NLTE MODELS

The asymmetries of various spectral lines observed in solar FLP are caused by moving plasma. Velocities determined by straightforward methods (like bisections) are not precise and in some cases are even incorrect (Heinzel et al., 1994). Therefore we need more exact techniques based on dynamic NLTE modelling in order to derive the plasma velocities and to explain observed asymmetries.

To solve the dynamic NLTE problem, we use here the accelerated lambda iteration method for multilevel atoms as recently developed by Rybicky and Hummer (1991). In order to evaluate the ionization structure of the atmosphere of FLP, preconditioned statistical equilibrium equations were linearized with respect to level populations and the electron density, according to Heinzel (1994). This multilevel NLTE method was implemented into a numerical code using C-language.

Here we want to demonstrate the effect of the downward moving plasma with constant velocity on the radiation emerging from a FLP-atmosphere. As an example, we take the run of temperature with depth for a weak flare atmosphere model F1 (Machado et al., 1980) and the macroscopic velocity which has non-zero constant value in the region of temperatures $10^4 - 2 \times 10^6$K. Using a three-level plus continuum hydrogen atom model, we have computed profiles of La, Lβ and Hα lines for three values of the downward velocity (10, 30 and 50 km s$^{-1}$). Results are plotted in Figure 5, where dashed lines correspond to dynamic models and the solid one to the static case. Complete frequency redistribution is used in these preliminary simulations since the flaring atmosphere has higher electron density which lowers the effects of photon correlations.

Figure 4: The energy change of 100 keV electron penetrating from a top of the loop into the VAL-C chromospheric layers, for the case without (full line) and with (dashed line) fixed electric current $J = 0.653$ Am$^{-2}$. © European Space Agency • Provided by the NASA Astrophysics Data System
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REFERENCES


Figure 5: Synthetic hydrogen line profiles computed for a dynamic model atmosphere of a weak flare F1.