ON THE OCCURRENCE OF BLUE ASYMMETRY IN
CHROMOSPHERIC FLARE SPECTRA

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Abstract. We present observations of optical spectra of a flare in which blue line asymmetry was
seen for more than 4 min close to the flare onset. The maximum blue asymmetry coincided with
the maximum of a hard X-ray and microwave burst. We discuss possible interpretations of the blue
asymmetry and conclude that the most plausible one is electron-beam heating with return current.
Although this process predicts downflows in the lower transition region and upper chromosphere, its
ultimate effect on the line profiles can be blue asymmetry: the upper layers moving away from us
absorb the radiation of the red peak thus lowering its intensity in comparison to the blue one.

1. Introduction

It is well known that chromospheric lines in solar flares show a red asymmetry, i.e., they are shifted towards the longer wavelengths and, in particular, their red
wings are more intense and more extended than the blue ones (see Švestka, 1976,
and references therein). A plausible explanation is that this asymmetry is due to
Doppler-shifted emission from downward-moving chromospheric condensations
(Ichimoto and Kurokawa, 1984; Fisher, Canfield, and McClymont, 1985; Fisher,
1987; Canfield and Galey, 1987). Simultaneously, a chromospheric evaporation
at the onset phase of the flare enhances the flare loop density (e.g., Fisher, 1987,
and references therein). This scenario seems to be supported by observations of
blue asymmetry in soft X-ray lines like Ca\textsc{xix} (Antonucci\textit{ et al.}, 1982, 1985;
Antonucci, Gabriel, and Dennis, 1984; further references in Antonucci, 1989) and
by quantitative comparisons of the chromospheric redshifts and coronal blueshifts
(Zarro and Canfield, 1989; Wülser, Zarro, and Canfield, 1992; Canfield\textit{ et al.},

However, there have been highly controversial results in observations of a
blue asymmetry in chromospheric lines near onsets of flares, and we want to
address this problem in the present contribution. First, in Section 2 we summarize
rather controversial observations made so far and in Section 3 we present new
observations related to this problem. Section 4 is devoted to a discussion of the
relevant electron beam heating models and in Section 5 we suggest an explanation
for the observed H\textalpha blue asymmetry using the NLTE transfer simulations. Finally,
in Section 6, we discuss possible reasons for the controversial observations of the

occurrence of blue asymmetry in flares and mention several other aspects of the blue-asymmetry problem.

2. Controversial Observations

During the early years of studies of the flare asymmetry, Švestka, Kopecký, and Blaha (1962), Sevěry (1968), and Švestka (1968) reported observations of a blue asymmetry which was seen quite often at the very onset of a flare. This blue asymmetry disappeared within one or just a few minutes and a more pronounced red asymmetry subsequently set in (also see Švestka, 1976). According to Švestka, Kopecký, and Blaha, who studied 244 spectra of 92 flares, red asymmetry was observed in 80% of flares and blue asymmetry was present in 23% of them, almost always only close to the flare onset. Because not all flares are observed in a spectrograph from their beginning, the onset phase, and thus the occurrence of the blue asymmetry, should be missed in many of them. This implies that, according to these authors, blue asymmetry should be commonly present in chromospheric spectra of flares close to their onsets.

In later years, however, some other authors did not confirm this conclusion:

Schoolman and Ganz (1981) studied the Hα line in 24 flares and found that all events with significant line shift were shifted towards longer wavelengths. However, they compared the peaks of the line profiles and not the far wings as Sevěry in the Crimea and Švestka and coworkers at Ondřejov did in the 60s.

Tang (1983) studied offband Hα filtergrams of 60 flares, and she saw blue asymmetry in only 3 of them, and only in peripheral flare parts. In several flares, according to Tang, red asymmetry was definitely seen in the filtergrams from the beginning of the flare, prior to the impulsive phase.

Ichimoto and Kurokawa (1984) studied spectra of 30 flares and particularly emphasized that they found no evidence for any predominancy of the blue asymmetry near the onset of the flare. ‘On the contrary’, they write, ‘almost all Hα flare spectra observed in this study show a striking dominance of the red wing over the blue wing from the onset of the flare’.

These results indicated that, for some unknown reason, the old observations at the Crimea and Ondřejov might have been erroneous. However, in the most recent years, these old results appear to have been at least partly reconfirmed, as several different authors again detected blue shifts in the chromosphere during the onset of flares.

Wülser (1987) studied Hα profiles of two flares with high time resolution of 5.4 s. While one of them showed red asymmetry all the time from the beginning of the flare, the other one revealed blue asymmetry for about half a minute at its onset.

Wülser and Marti (1989), though they did not report any blue asymmetry prior to the flare maximum, found that in some flare kernels the intensity in the blue wing peaked somewhat earlier than in the red wing, just a few seconds after the
hard X-ray maximum.

Canfield et al. (1990) detected regions with blueshifted H\(\alpha\) emission early in the impulsive phase in two of the five flares studied by them. The blueshifts correlated in time with hard X-ray emission and had lifetimes between 1 and 2 min. These authors have proposed three different explanations for the blue asymmetry, all in terms of an upward motion of the cool plasma.

Blue asymmetry of the H\(\alpha\) self-reversed profile was also detected by Graeter (1990).

Fang, Hiei, and Okamoto (1991) studied two flares in the Ca \(\ic\) K line and, again, they found blue asymmetry in one of the kernels in one flare, while in the other flare only red asymmetry was observed.

Graeter and Kucera (1992) observed a 3B/X1.6 flare with high temporal resolution of 2.3 s and detected a blueshifted region at the beginning of the observations, although the earliest onset of the flare had been missed.

Blueshifts and redshifts have also been detected in various locations in one flare observed by Cauzzi et al. (1992) at Sacramento Peak, confined to several small kernels.

Quite recently, Ji et al. (1994) observed another flare with high resolution both in space and time. They found blue asymmetry during the onset phase of the flare, but only in some parts of the flare, and often for a very short time, at some places for less than 10 s.

Schmieder et al. (1987) report blue asymmetry in bright ribbons at footpoints of post-flare loops in eruptive flares, but this asymmetry is probably related to the process of ‘gentle evaporation’ late in the flare development, and thus it seems quite different from all the other observations mentioned above, which were made during the impulsive phase of flares.

All the observations summarized above refer to blueshifts of flare patches and kernels seen in emission. Some authors also observed blueshifts of absorption features, but those are related to the erupting filaments in the onset phase of flares and thus they are not relevant to this study. Though some of the reported blue-shifting emission features might possibly be the dense parts of a rising filament as well (e.g., that one discussed by Graeter and Kucera, 1992), most of the blueshifts were located far from any filament, and thus without any relation to the destabilized cool material in the chromosphere.

3. Observations of the SN Flare of 4 October, 1991

3.1. Optical spectra

The newly rebuilt Multichannel Flare Spectrograph (MFS) at Ondřejov Observatory (Kotrč, Heinzel, and Knížek, 1992) was used to take a series of photographic spectra of a SN/M1.2 flare on 4 October, 1991 (at S18 W30), starting very close to its reported onset at 09:33 UT (Solar Geophysical Data, 1992). Table I gives the observing times and position of the slit. At the onset of the flare, five spectra
TABLE I
Optical spectra characteristics

<table>
<thead>
<tr>
<th>Spectrum No.</th>
<th>Position (kernel)</th>
<th>Time UT (h:m:s)</th>
<th>Asymmetry (all lines)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>09:36:53</td>
<td>max. blue</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>09:37:33</td>
<td>blue</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>09:38:48</td>
<td>blue</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>09:40:02</td>
<td>weak blue</td>
</tr>
<tr>
<td>5</td>
<td>A</td>
<td>09:41:19</td>
<td>weak blue</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>09:43:14</td>
<td>red</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>09:43:35</td>
<td>max. red</td>
</tr>
<tr>
<td>8</td>
<td>B</td>
<td>09:44:38</td>
<td>red</td>
</tr>
</tbody>
</table>

Fig. 1.  (a) \( \text{H}_\alpha \) filtergram of the active regions NOAA 6850 and 6853 where the October 4, 1991 flare occurred, taken at 09:37:08 UT, close to the time of spectrum No. 1. The arrows indicate the positions of the two kernels A and B in which the spectra were taken. (Bialkow Observatory, courtesy of B. Rompolt.) (b) A soft X-ray picture of the flare in its late gradual phase, taken by the SXT on Yohkoh at 10:14:28 UT. A photospheric picture is shown for a comparison. (Courtesy of T. Hirayama and T. Watanabe.)

were taken in the emission kernel A, later on three additional spectra correspond to position B slightly shifted along the flare ribbon (see Figure 1(a)).

The spectra were recorded simultaneously in five channels and the following spectra lines have been detected during the flare development: hydrogen Balmer lines \( \text{H}_\alpha \) – \( \text{H}_\epsilon \), \( \text{He I D}_3 \), and \( \text{Ca II H} \) and K lines. Spectra No. 1–5, taken at kernel A, clearly indicate blue asymmetry (an example in Figure 2) in all observed lines early in the impulsive phase. On the other hand, spectra No. 6–8 from kernel B are representative for the typical red asymmetry occurring before the flare maximum (example in Figure 3). Temporal variation of the line asymmetry (qualitatively the
same in all lines) is indicated in Table I.

In Figure 2, at 09:36:53 UT, the blue asymmetry in the Balmer lines, if interpreted by upward mass motions deduced from the bisector method (as in Canfield et al., 1990), corresponds to rising speeds of 8–23 km s\(^{-1}\) along the line of sight. The lower limit corresponds to the shift of the line center, the upper limit to the centroid of the line profile at the far wings. In the Ca II K line, blue asymmetry also appears at that time, though corresponding to lower speeds of 6–9 km s\(^{-1}\). These rather low velocities and the inspection of the H\(\alpha\) filtergrams preclude the presence of any bright surge in position A, so that we ascribe the blue asymmetry to the flare kernel itself.

We may note that the blue asymmetry in H\(\alpha\) observed at the onset of the October 4, 1991 flare is qualitatively similar to that detected by Graeter (1990) in the flare of September 8, 1988 (his kernel A).
3.2. X-RAY DATA

Figure 4 shows the time history of hard X-ray emission as detected by GRO-BATSE in channels 25–100 keV (flares No. 1382 and 1383). Eight optical spectra were taken during the flash phase (before the maximum in GOES 1–8 Å X-rays), and the times of six of them are marked by arrows in Figure 4 (compare Table I). The spectrum No. 1, which shows the largest observed blueshift, coincides in time with the maximum of the second hard X-ray burst. Unfortunately, although our observations were made during the first coordinated MAX’91 – Yohkoh campaign (Kiplinger, 1992), no simultaneous flare data are available from Yohkoh due to satellite night.

According to observations made in other active regions by Dwivedi et al. (1984) it is likely that the maximum of hard X-rays comes from a region where the flare emission approaches a sunspot and at kernel A we may see the opposite footpoint of a loop rooted in that position. In the Hα picture shown in Figure 1(a), taken
between our spectra No. 1 and 2, we see two brightenings in sunspot penumbrae, to the NW and SW from kernel A, but it is difficult to decide which of them was connected to A. Both Figure 1(a) and late gradual-phase pictures made by the SXT on Yohkoh (Figure 1(b)) show two flare ribbons, separated in Hα by a faint dark filament which marks the neutral line. Therefore, one would expect that kernel A is the northern footpoint of a flare loop extending to the SW penumbral brightening. However, the Yohkoh pictures, though admittedly showing a much later phase of the flare, rather indicate a loop connection to the NW brightening (Figure 1(b)), where an X-ray brightening penetrates into the sunspot. Also a loop connection to kernel A seems to be indicated but, as already mentioned, there are no Yohkoh pictures close to the time when the spectra were taken.

3.3. RADIO OBSERVATIONS

On radio waves this flare was observed by the 2–4.2 GHz Ondřejov radiospectrograph (Figure 4). At the times of the first two hard X-ray emission peaks, during 09:34:20–09:35:20 and 09:36:40–09:37:20 UT, we observed relatively weak broadband radio bursts. The following broadband radio burst, during 09:42:30–09:43:10 UT, was more intense and its structure mirrored the double peak of the corresponding hard X-ray emission (Figure 4). Thereafter, simultaneously with other hard X-ray bursts, fast drift bursts with positive frequency drift were detected. The frequency drift of the first fast drift burst at 09:43:50 UT was 4 GHz s⁻¹, and the radio emission of this burst ended at 3.9 GHz.

Due to the time coincidence of all observed radio bursts with hard X-rays, it is probable that all of them, including the broadband ones, were fast drift bursts. The only difference may be in the magnitude of the frequency drift. Due to the limited time resolution of our observations (0.1 s), any frequency drift faster than 10 GHz s⁻¹ is difficult to measure. Apparently, prior to 09:43:10 UT the frequency drifts were too fast to be detectable, and only after 09:43:40 UT can we distinguish the somewhat slower positive frequency drifts in the recorded bursts.

In accordance with the paper of Benz et al. (1992), we interpret these fast drift bursts as the radio manifestation of electron beams propagating downwards into deep atmospheric layers. The tendency for the frequency drift to decrease at later times can be interpreted by an increase of the density scale-length, which is in agreement with the evaporation scenario: the evaporation and heating of the plasma decrease the density difference between the top and the foot of a loop. Our estimated density scale-length at 09:43:50 UT is about 34 000 km, close to values derived by Benz et al. (1992).

4. Flare Heating Models

4.1. SCENARIO OF CANFIELD ET AL.

Similarly to our case, Canfield et al. (1990) observed blue asymmetry in time correlation with hard X-rays, although there were no X-ray images to confirm a
Fig. 4. Composite temporal evolution of the 4 October, 1991 flare in hard X-rays (BATSE, above) and GHz radio (Ondřejov, below). Note that the BATSE intensity scale changes at 09:41 UT. In the radio data, the plot of time variations at three different frequencies is replaced by a dynamic spectrum plot after 09:42 UT, to demonstrate the frequency drifts. Arrows indicate the times at which the optical spectra were taken by the MFS (see Table I).
spatial correlation as well. The systematic occurrence of the blue asymmetry early in the impulsive phase indicates that it really appears at places where nonthermal electrons precipitate from the corona into the chromosphere. As Canfield *et al.* have pointed out, rapid heating of a small part of the middle chromosphere could create an unbalanced local pressure excess and drive overlying chromospheric material upwards. However, to be seen in Balmer lines, this material must stay cool, so that it is not evaporated fast.

A typical electron stream with a large amount of flux in the 10 keV range would deposit its energy predominantly in the upper chromosphere and thus heat these layers so fast that their emission can never appear in Balmer lines. What one needs is an electron spectrum with higher mean energy and small flux at lower energies (high energy cutoff) so that electrons would go through these upper layers, being stopped deep in the chromosphere. In such a case, the overlying layers might begin to rise before hydrogen in them is ionized to such an extent that the Balmer lines disappear.

As Canfield *et al.* also perceived, such conditions might occur, but it seems unlikely that they would occur too often. However, this is what we actually observe: the blue asymmetry is detected only in a few localized areas, and only in some flares; in some such areas the rising chromospheric gas is heated so fast that the blue asymmetry disappears after a few seconds. At most places, and in most flares, we do not see the blue asymmetry at all: either, because the spectrum of the electron stream, heating the kernel, is not hard enough; or, because the chromospheric flare patches are heated by conduction. In both these cases the upper chromospheric layers become too hot from the very onset of the chromospheric heating and evaporation.

In order to keep the chromospheric temperatures rather low and simultaneously to see Hα in emission, Canfield *et al.* (1990) suggest that the preflare coronal pressure must be strong enough. However, this may contradict the expected deep penetration of the electron beams. Quantitative numerical simulations are thus required to check the above scenario of a blue asymmetry formation.

### 4.2. Electron-Beam Heating with Return Current

The presence of downward-streaming superthermal electrons in the flare of 4 October, 1991, confirmed by hard X-ray and GHz radio bursts, speaks indeed in favour of a blue-asymmetry model related to electron beams as Canfield *et al.* (1990) concluded. However, we want to suggest here another scenario of the blue-asymmetry formation, taking into account effects of the return current.

It follows from recent numerical simulations by Karlický and Hénoux (1992) that just at the very beginning of the flare, i.e., at times when the blue asymmetry is observed, the return current effect on the electron beam bombardment is most important. While the coronal temperature increases during the flare, the chromosphere remains much cooler ($T \approx 10^4$ K), i.e., it represents a jump in electrical resistivity for the electron beam. Therefore, the energy deposit of electron beams
under the influence of a return current takes place in a very narrow layer just in
the vicinity of the transition region. As a result of this energy deposit, we obtain
downflows at the lower transition region and upper chromosphere and upflows in
the upper transition region (see Karlický and Hénoux, 1992). If the return current is
neglected, which is the case in most numerical simulations, the energy is deposited
in a broader interval of depths, including rather deep chromospheric layers, as
suggested in the above scenario of Canfield et al.

Due to the relatively low density of the upper transition region and narrowness
of an evaporating layer, the onset evaporation is relatively weak. However, as a
result of the beam-heating continuation, the transition region will be shifted down to
higher densities and the evaporation will become stronger. Simultaneously, the role
of the return current will decrease and the relevant hydrodynamical processes will
resemble a standard downward-moving condensation as described by MacNeice
et al. (1984) and Fisher (1989) in their models without return current. This situation
predicts the red asymmetry in the Hα line (Canfield and Gayley, 1987).

In the next section we shall demonstrate how the specific downflow velocity
field, predicted by return-current models, can produce blue asymmetry in the Hα
line.

5. Dynamic NLTE Simulations

We have modified the atmospheric NLTE code developed by Heinzel (see, e.g.,
Heinzel, Gouttebroze, and Vial, 1987) to study the behaviour of the Hα line
formation in a dynamic flare atmosphere. Since we use here several simplifying
assumptions, we do not aim at the best fit with the observed profiles, but rather we
want to demonstrate the general applicability of this process as the principal cause
of the blue asymmetry detected near the onset of the flare.

The self-reversed Hα line profile observed at the beginning of the flare of
4 October, 1991 (Figure 2) corresponds to a rather weak flare and therefore we
start from the flare model F1 of Machado et al. (1980) and Avrett, Machado, and
Kurucz (1986). Our observed Ca II K profile is not reversed as in Avrett, Machado,
and Kurucz (for flare model F1), but that reversal was probably due to neglect
of turbulent broadening in the computations (Avrett, private communication). On
the other hand, we have observed a weak absorption in the He II D3 line, which is
consistent with the F1 model.

Using a five-level-plus-continuum hydrogen model atom, we have computed
the Hα line profile emerging from the static atmosphere F1 (Figure 5(a), symmet-
rical long-dashed profile). Further, to simulate the effect of velocity fields on the
line profile, we prescribe the run of macroscopic flow velocity with the temperature
and solve the transfer equation for such a dynamic atmosphere, using previously
evaluated level populations from model F1. This is possible as a first approximation
because the velocities within the Hα line-forming region are not large – see Fig-
ure 5(b). Machado et al. (1980) indicate that the Hα line core is formed at the top
of the chromosphere at temperatures between 8500 and 18 000 K.) The structure of the velocity field used in our NLTE simulations is qualitatively consistent with the concept of downward-moving chromospheric plasma. As a guide, we have used the pulse-beam heating model of Karlický and Hénoux (1992) with the return current effect, which predicts expected plasma evaporation (upflows) and downward flows in the transition region and upper chromosphere. The downflow velocities decrease from the lower transition region towards the chromosphere and at \( T \sim 10^4 \) K they approach zero (see Figure 5(b)). This type of velocity field corresponds to the impulsive heating by electron beams, a situation we observe at 09:36:53 UT. Note that in such a case the non-thermal collisional processes should be included into the statistical equilibrium equations, which leads to an enhancement of the \( \text{H}\alpha \) intensity (Fang, Hénoux, and Gan, 1993). In our exploratory simulations we do not include these nonthermal collisions and simply use the temperature structure of the F1 model just to get a rough fit to our observed intensities. In fact, the beam fluxes adopted by Fang, Hénoux, and Gan and giving significant \( \text{H}\alpha \) enhancement seem to us rather strong for the event studied in this paper.

Velocities as displayed in Figure 5(b) have been used in connection with model F1 to produce the asymmetrical line profile shown in Figure 5(a) (upper full line). The computed \( \text{H}\alpha \) profile exhibits a blue asymmetry which is similar to that detected in our spectra. The explanation for this striking behavior (i.e., downflows producing blue asymmetry) is simple: the upper layers moving away from us do absorb the radiation from the red peak thus lowering its intensity compared to the blue peak (note a redshifted self-reversal absorption feature in both simulated and observed \( \text{H}\alpha \) profiles). The reverse effect is well known for the case of expanding atmospheres, where the red asymmetry of emission profiles was obtained (Hummer
and Rybicki, 1968; Cannon, 1985). In Cannon’s (1985) textbook (pp. 309–312), the reader may find a simple illustrative explanation of these effects. Let us note in this respect that the red asymmetry caused by an expanding flare atmosphere was already discussed a long time ago by Waldmeier (1941), Švestka (1951), and Severny (1968). Quite recently, Gan, Rieger, and Fang (1993) have also shown that for their downward-moving, semi-empirical condensation, the Hα line may exhibit, under specific circumstances, blue asymmetry. Actually we have tried various velocity fields of the type shown in Figure 5(b), and almost always we have arrived at blue asymmetry. However, for more intense flares, with unreversed emission Hα profiles and non-negligible velocities in the middle chromosphere, we would expect a typical red asymmetry as observed, e.g., at 09:43:35 UT. In any case, our simulations predict a certain velocity gradient, which is in qualitative agreement both with our multiline observations and with recent conclusions made by Falchi, Falciani, and Smaldone (1992).

Another problem is that the synthetic Hα profiles, having a deep reversal, frequently exhibit very narrow peaks. Such sharp peaks are not usually observed and thus various authors have tried to broaden their theoretical profiles with macroturbulent motions (e.g., Fang, Hénoux, and Gan, 1993). This macroturbulence cannot be excluded, but on the other hand the observations are usually taken under moderate or even poor seeing conditions, which naturally leads to a mixing of the flare and the background (enhanced chromospheric) profiles (see also the discussion in Wülser and Marti, 1989).

In order to check up on this, we also used (following Gayley, 1990) a linear mixture of the two profiles, i.e., our computed dynamic profile and an enhanced chromospheric profile corresponding to the nearest surroundings of the flare kernel (higher short-dashed line in Figure 5(a)). Using equal weights for both profiles, the resulting Hα profile (lower full line in Figure 5(a)) is in relatively good agreement with the observed one shown in Figure 2. Indeed, our observations were made under moderate seeing conditions and the flare kernel A was rather small. For a more quantitative analysis, we have to consider both the mixing ratio and macroturbulent parameters in order to fit the lines of various chemical species (Ca II lines will be more sensitive to macroturbulence than hydrogen lines).

Finally, our NLTE simulations indicate that the bisector technique, mentioned above and used by many authors, can sometimes lead to quite misleading results. Any ‘straightforward’ interpretation of the blue-shifted bisector gives upflow velocities, while in our interpretation the actual velocity field corresponds to downflows.

6. Discussion and Conclusions

First, let us ask what may be the reasons for discrepancies in observations of the blue asymmetry made by different authors.

One reason seems to be the resolving power of the observing instrument, as Ji et al. (1994) have pointed out; essentially all spectral observations that were
carried out during the onset phase of flares with high resolution both in time and space detected blue asymmetry in at least some of the observed flares. That clearly implies that in many cases the occurrence of blue asymmetry is either short-lived or restricted to small parts of the flare or both.

Another factor may be the seeing. One should not forget that the original discoveries of the blue asymmetry in the Crimea by Severny and at Ondřejov by Švestka and coworkers were made by spectrographs specifically constructed for photographs of flare spectra, with very short exposure times in the optical part of the spectrum, which partly eliminates the effects of atmospheric seeing. Note that the MFS is essentially the same instrument used by Švestka and coworkers.

And, last but not least, both in the Crimea and at Ondřejov continuous visual flare patrols were carried out during selected activity intervals so that for the flares observed during these intervals very few flare onsets were missed. If such a strict regime of live flare patrol is not maintained, one rarely is able to start taking spectra in the very initial phase of a flare which, as it seems, is the only time when the blue asymmetry can be detected. Only with new CCD techniques it is now possible to follow a selected active region continuously so that, if a flare occurs, it is recorded from the very beginning. Such techniques have already been used by some above-mentioned authors, who indeed recorded blue asymmetry in the Hα line.

As a matter of fact, the most controversial observation is that by Tang (1983): she saw the flares in filtergrams from their onsets, because the Big Bear photographic high-resolution patrol is continuous; she saw them with high spatial resolution, as Big Bear pictures have one of the best resolutions in the world; seeing should have been good, because the Big Bear solar tower is on a pier in Big Bear Lake; she could see, at the same time, all the kernels, whereas a spectrograph can provide a spectrum only of those kernels which are on the slit. And, still, she detected blue asymmetry only in 5% (3 out of 60) of the flares. Of course, in contrast to all the other authors, she did not take spectra: she just compared images taken ±1 Å and ±2 Å distant from the Hα line center. Because the blue asymmetry is usually a weak effect, it might be missed if systematically, for some reason, the line were not properly centered, which seems unlikely. Tang could also have overestimated the expected size and duration of the blue-shifted patches and, therefore, miss some of them. However, the actual reason may follow from our present observations, which show that the blue asymmetry can manifest itself only by a somewhat enhanced blue peak, with no significant emission far in the wings. Since this peak is located around −0.7 Å, it can be missed by the Big Bear filter tuned to −1 and −2 Å. This also shows that the term ‘asymmetry’ may have different meaning in different cases: either it is the strong enhancement of emission in one wing (as reported by the early observers), or it is just an excess in one of the two peaks of the self-reversed profile. Sometimes the whole line is also shifted.

In any case, summarizing all these observations, one arrives at the conclusion which fits all the data: the blue asymmetry that appears in the initial phase of a
flare (near the onset of the impulsive phase) is observed only in small parts of
the flare, and for a short time, sometimes, according to Ji et al. (1993) for less
than 10 s. There are definitely flares where blue asymmetry is not observed at
all, but the number of such ‘purely redshifted’ flare events clearly decreases with
good coverage of the flare onset, enhanced resolution in space and time, and with
increasing spectral resolution.

Already Švestka, Kopecký, and Blaha (1962) noted that at the same time that
blue asymmetry appears in a flare kernel, other kernels may show red asymmetry,
and this has been confirmed by other authors as well (Tang, 1983; Canfield et al.,
1990; Cauzzi et al., 1992, Ji et al., 1993). Both Ji et al. and Canfield et al. have
noted that the short-lived blue asymmetry was not followed by red asymmetry in
the same kernel – it just disappeared and red asymmetry appeared elsewhere. With
respect to these observational results it is difficult to speculate whether our kernel A
would develop into red emission (which was detected in the other kernel B later on),
although both of them seem to belong to the same ribbon and thus could correspond
to similar physical conditions. However, rather stochastic and uncorrelated heating
may take place within the individual loops belonging to the same arcade.

The relatively long duration of the blue asymmetry, about four minutes, which
is much longer than any individual beam injection, indicates that there are many
pulses of electron beams, possibly in different elementary (spatially unresolved)
loop structures and stochastic in time. This is indicated in the fine structure of
hard X-ray emission. In such statistical bombardment, each pulse beam is under
the influence of return current effects. However, one has to keep in mind that
the hydrodynamic response of the solar atmosphere has a smoothing effect (as its
characteristic time is much longer than the duration of a single pulse beam) and thus
we expect that a sequence of pulse beams will drive relatively smooth downflow
of plasma in the transition region and upper chromospheric layers. So we do not
expect any short-lived blue asymmetry variations (in any case, our time resolution
would not permit us to detect them).

On the theoretical side, the proposed model of blue asymmetry related to the
electron beam bombardment and return current effects properly explains the rare
observations of blue asymmetry by the short duration of these processes and a
specific temperature-velocity profile in the transition region and the upper chromo-
sphere. We expect that the duration of blue asymmetry decreases with increasing
beam flux, because for very intense electron beam fluxes the transition region shifts
in a very short time (a few seconds) to high densities where downward motions lead
to the typical red asymmetry. We further suggest that the blue asymmetry is very
sensitive not only to electron beam parameters, but also to the preflare conditions
in the flare loops and only detailed numerical simulations can reveal all aspects of
these complex processes.

We have demonstrated how the downward plasma flows, driven by the electron
beam heating with the return current, can produce the observed blue asymmetry in
the Hα line. Seeing effects can, however, distort the profiles and also great caution
has to be paid to any direct interpretation of the asymmetry using the bisector technique. For the future we plan to analyze our MFS multi-line observations in much greater detail, using new radiation-hydrodynamical simulations of the flare heating and NLTE synthesis of the line profiles of various atomic species.

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