SPECTRAL LINE ASYMMETRIES AND DOPPLER SHIFTS OF THE 1984 JANUARY 26 FLARE*

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I. INTRODUCTION

It has been recognized since the 1940s that flare emission lines are usually asymmetric[1]. Svestka summarized in his book[2] the spectral observations before the 1970s. His main results are as follows: (i) for most flares, a short-lived blue asymmetry appears at the flare onset, and subsequently a red asymmetry sets in and persists till after the flare maximum phase; (ii) for some flares, spectral lines in different regions may have the opposite asymmetries even at the same time; (iii) in general, there is no shift at the line center when the line asymmetry sets in. Many explanations have been proposed, but none can deal with all the aspects of the observed phenomena[2]. If the asymmetry is attributed purely to the mass motion of atmospheric materials, the Doppler velocities derived from the hydrogen Balmer lines and various metal lines are usually inconsistent[3]. Thus, the asymmetry of flare emission lines was ever regarded as the most puzzling problem in flare spectra[2].

With the advancement of space observation technique beginning in the 1970s, more and more high temporal and spatial resolution flare spectra have been obtained, and the knowledge about the flare dynamic process is becoming abundant. Through the soft X-ray observations of CaXIX and FeXXV helium-like ions, Antonucci et al.[4, 5] found that the spectral lines have blue-shifted components in the flare impulsive phase, and thus concluded that some hot plasma in the chromosphere may move upward into the corona at a velocity of hundreds of km/s, which supports the hypothesis of chromospheric evaporation. Ichimoto and Kurokawa[6] made the Hα spectroscopic observations of flare bright kernels with high resolutions. The results show that strong red asymmetries exist in Hα lines, which they regarded as the consequence of the movement of a chromospheric condensation towards deeper layers at a velocity of tens of km/s. Fisher et al.[7] modeled theoretically the thermal response of flare atmosphere under the bombardment of non-thermal electrons, and confirmed that the high pressure caused by the overheating in the chromosphere-corona transition region could drive the chromospheric upflows (i.e. the chromospheric evaporation) and downflows (i.e. the chromospheric condensation). Canfield et al.[8] further verified from

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combined spectral observations that the upward momentum of chromospheric evaporation is balanced by the downward momentum of chromospheric condensation. Now, these dynamic properties for the upper atmosphere during flares seem to be widely accepted, and are supported by more and more up-dated observations[9]. However, there exist opposite results. The observation of McClements and Alexander[10], for example, shows that the CaXIX lines have no or only very small blue-shifted components.

Contrary to the lines formed in the upper layers, those formed in deeper layers have not called much attention. Some observations[11] have clearly indicated that, the temperature minimum region may be heated to different extents during flares. Thus, in order to investigate the mass motion of the lower atmosphere and get a global figure of the flare dynamic process, we should analyze carefully the characteristics of the lines formed in the lower layers.

II. Observations and Reduction of Data

Since the foundation of the Solar Tower Telescope in Nanjing University, the spectra of several decades of flares have been obtained. In the vicinity of CaII H and K lines, there exist various absorption lines of neutral or low-ionized non-hydrogen elements. Only for the 1984 January 26 flare, emission features appeared evidently in the core of some strong metal lines. According to the SGD record, this flare occurred at the position N16E26 in the solar disk, with the importance being SB; the flare began at 00 : 35 UT, ended at 01 :34 UT, with the maximal time being about 00 : 47 UT. The flare spectra at eight sequential times were recorded, which cover the maximum phase. Table 1 gives the accurate times of this spectral observation.

Table 1

Time Series of Flare Spectral Observations

Observation No.	t1	t2	t3	t4	t5	t6	t7	t8
Observation Time (UT)	0 :45 :10	0 :46 :36	0 :47 :45	0 :49 : 55	0 :53 :25	0 :57 :40	1 :01 :35	1 :13 :45
	before the maximum phase		after the maximum phase					

All the photographic plates were scanned by use of PDS, and then analyzed by use of the IRAF/NOAO/ONEDSPEC software package in the Sun Work Station. Three sharp local peaks with wavelengths being 3883.51, 3901.74 and 3913.09 Å were selected to be the reference points. Suppose that the mean pixel value of the reference points for the flare spectra is R_f (pix), that for the undisturbed (quiet Sun) is R_q (pix); accordingly, the pixel value of the measured line for the flare spectra is S_f (pix), that for the undisturbed is S_q(pix); the dispersion power is $\partial\lambda/\partial x$ (Å/pix). Then the displacement of the flare lines relative to the undisturbed is

$$\Delta\lambda(\text{A}) = [(S_f - R_f) - (S_q - R_q)]\,\partial\lambda/\partial x. \tag{1}$$

From Eq.(1), we assumed that the reference points in flare spectra had no Doppler shifts. Additionally, we also measured the asymmetry of the flare excess line profiles (i. e.

the flare line profiles subtracted by the preflare ones).

Table 2 presents the results of six lines with core emissions and nine other lines without core emissions. It should be stressed here that in order to determine accurately the line center we used a method of fitting Gassian profile to this line.

Table 2

Asymmetries and Line Center Doppler Shifts (10^{-2} Å) of the Flare Spectral Lines

Element	Wavelength (Å)	Core Emission	Asymmetry[a)]	Line Center Shift							
				t1	t2	t3	t4	t5	t6	t7	t8
FeI	3886.3	yes	–	−0.343	−1.349	−2.223	−1.786	−1.447	−1.856	−0.571	−0.208
CH	3892.6	no	–	−0.006	−0.235	0.074	−0.136	−0.229	−0.165	−0.324	0.068
FeI	3897.4	no	–	−0.531	−0.449	−0.389	−0.408	−0.349	−0.302	−0.560	0.157
FeI	3899.7	yes	b	−1.655	−1.352	−2.882	−1.615	−0.760	−0.588	−0.960	−0.027
VI	3902.2	no	–	−0.197	0.080	−0.013	−0.209	−0.012	0.009	−0.193	0.136
FeI	3903.9	no	–	−0.411	−0.431	−0.449	−0.246	−0.309	−0.142	−0.242	−0.076
SiI	3905.5	yes	wb	−1.969	−1.743	−2.384	−2.485	−1.501	−2.463	−2.020	0.228
CrI	3908.7	no	–	−0.302	−0.330	−0.355	−0.293	0.086	−0.156	−0.421	0.345
Ch	3910.5	no	–	−0.267	−0.555	−0.411	−0.616	−0.321	−0.488	−0.437	−0.163
NI	3913.0	no	–	−0.394	−0.346	−0.253	−0.082	−0.241	−0.114	−0.492	0.075
FeI	3917.2	no	–	−0.614	−0.445	−0.501	−0.303	−0.368	−0.309	−0.348	−0.029
FeI	3922.9	yes	b	−1.301	−1.731	−2.374	−1.372	−0.292	−0.723	−1.584	−0.032
TiI	3924.5	no	–	−0.202	−0.456	−0.587	−0.390	−0.226	−0.208	−0.677	0.043
FeI	3927.9	yes	–	−1.078	−1.635	−2.451	−1.542	−0.409	−1.696	−1.121	−0.079
FeI	3930.3	yes	–	−1.273	−1.272	−1.983	−1.206	−1.814	−2.830	−1.940	−0.258

a) b: blue asymmetry; wb: weak blue asymmetry; –: no obvious asymmetry.

III. Results and Discussion

The results in Table 2 can be summarized as follows:

(i) For all the lines with obvious core emissions, the line core is centrally reversed, and there is a slight blue shift in the line center with its maximal value being 0.02 ~ 0.03 Å. The blue shift value varies according to the same process as the development of the flare, that is, increasing to the maximum, then decreasing, and vanishing in the later main phase (t8 time). The blue shift value peaks at t3 time, accompanying roughly the brightness maximum phase (slightly after t2 time).

(ii) For all the metal or non-metal absorption lines without core emissions, there is no or only very small blue shift in line centers.

(iii) Only two iron lines (λ3899.7 and λ3922.9) exhibit evident blue asymmetries in the maximum phase; the silicon line λ3905.5 has only weak blue asymmetry; the other lines (with or without core emissions) have roughly no asymmetries.

It is very interesting that the above results seem to run counter to the previous conclusions[2], i. e. the red asymmetries dominate and the line centers have no shifts. Correspondingly, we raise the following explanations :

(i) For spectral lines with core emissions, the forming region of line cores is relatively higher (i. e. in the lower chromosphere, temperature minimum region and the upper photosphere). During the occurrence of the flare, this region may be heated to a higher temperature (e.g., non-thermal electron bombardment, XUV irradiation, chromospheric radiative backwarming), and this can consequently yield a local enhancement of the gas pressure. Under some initial conditions, this high pressure can cause the upward motion of a part of the atmospheric materials, at a velocity with the peak value 1.5 — 2.5 km/s, producing a 0.02 — 0.03 Å blue shift and sometimes blue asymmetry for these lines.

(ii) During the flare onset, a condensation may be formed at the top of the chromosphere, and then spread downward. Denote by I_v^0 the line intensity just below the condensation, and by I_v that after passing through it; the condensation is optically thin, with the optical thickness τ_v and source function S_v, we have

$$I_v = I_v^0 e^{-\tau_v} + S_v(1-e^{-\tau_v}) \approx I_v^0 + (S_v - I_v^0)\tau_v. \qquad (2)$$

Because the temperature within the condensation is relatively lower[7], we have generally $S_v < I_v^0$ and consequently $I_v < I_v^0$, that is, the condensation has an absorption property. So, when the condensation moves downward, it can make the lines red-wing absorbed, producing the line blue shifts and blue asymmetries. Fisher's study[12] indicates that when the condensation spreads downward it may accumulate gradually chromospheric materials while its velocity decreases. This dynamic property of the condensation is consistent with our observations of the line center blue shifts.

(iii) Those lines without core emissions have a relatively deeper forming layer, which is less affected by the flare heating so that their differences from the undisturbed ones are very small.

Between the first two explanations, we are inclined to the second one, as the observational and theoretical study of the dynamic process for the upper atmosphere is becoming perfected, while the knowledge about the lower atmosphere is still insufficient. However, a main problem is that the theoretical life time of the condensation[12] is too short compared with the observed. Following Fisher[12], we suggest that this inconsistency is partly due to the insufficiency of the spatial resolution in observations. Moreover, it should be stressed that the above data are only for one particular point in the flare region; for other points, different asymmetries and Doppler shifts may appear, just as our precursors have pointed out[2]. In a word, in order to understand completely the global dynamic process in the flare atmosphere, more high resolution observations and detailed theoretical studies are required.

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