The Magnetic and Velocity Fields of Solar Active Regions
ASP Conference Series, Vol. 46, 1993
Harold Zirin, Guoxiang Ai, and Haimin Wang (eds.)

DIAGNOSTICS OF THE VELOCITY FIELD IN THE LOWER ATMOSPHERE OF SOLAR FLARES

FANG CHENG, YIN SU-YING, DING MING-DE
Department of Astronomy, Nanjing University, Nanjing, China

EIJIRO HIEI
National Astronomical Observatory, Mitaka, Tokyo 181, Japan

ABSTRACT Based on the analyses of CaII K line profiles of 12 solar flares, the characteristics of the red asymmetry of CaII K line are summarized. Non-LTE calculations indicated that a downward motion of plasma above the temperature minimum region (TMR) as well as a contracting motion of plasma toward TMR can well explain the red asymmetry observed at the K_1 positions. The typical velocity is 10–30 km s^{-1}. This result is consistent with the observations of metallic lines of solar flares.

INTRODUCTION

Recent observations show that during the impulsive phase of flares, the H_α line has a strong red asymmetry, which implies a downward velocity of 40–100 km s^{-1} in the upper chromosphere (Ichimoto and Kurokawa 1984; Canfield and Gunkler 1985). Our observations (Fang et al. 1986, Gan and Fang 1987) also indicate that as the impulsive phase develops, the red asymmetry of CaII K line increases. That is, the intensity of the red wing at K_{1r} (I_r) is stronger than that of the blue wing at K_{1b} (I_b), and the distance between K_{1r} and the line center ($\Delta\lambda_r$) is larger than that for K_{1b} ($\Delta\lambda_b$). Generally, the red asymmetry reaches its maximum before the maximum of the K line intensity, and then gradually decreases.

In this paper, based on the analyses of CaII K line profiles of 12 solar flares, the characteristics of the red asymmetry of K line are given in detail. An explanation of the asymmetry of CaII K line is also proposed.

THE CaII K LINE ASYMMETRY

The spectral data of the 12 flares, of which eight were observed with the solar tower of Nanjing University and four at the Norikura station with a 25-cm coronagraph have been analysed. The time resolution was about 20–30 s. The characteristics of the CaII K line asymmetry can be summarized as follows: (1) After the onsed of flares, $\Delta\lambda_r$ becomes larger than $\Delta\lambda_b$. The value of $\Delta\lambda_r - \Delta\lambda_b$ is typically 0.1–0.4 Å. (2) After the onset of flares, I_r becomes larger than I_b. The value of $(I_r - I_b)/I_c$ is typically 0.01–0.04. (3) Both of the mentioned red asymmetries generally reach their maximum before the maximum of the intensity at the K line center. The time delay is typically several minutes. (4) Generally the asymmetry parameters $\Delta\lambda_r - \Delta\lambda_b$ and $(I_r - I_b)/I_c$ increase with R_{max}, but it seems that $(I_r - I_b)/I_c$ has a saturation when R_{max} becomes larger than 1.

INTERPRETATION

The semi-empirical models of F_1 and F_2 given by Machado et al. (1980) have been used as two initial models. A terraced velocity distribution ar ound the TMR, as shown in Figure 1, has been adopted. The velocities between layers numbered m_a+2 and m_b-2 and that between m_b+2 and m_c-2 are chosen so as to be constant, V_{m_1} and V_{m_2}, respectively. The downward velocity is prescribed as being negative. For a given initial model and a prescribed velocity pattern, the statistical equilibrium eqations as well as the transfer equations for hydrogen and ionized calcium have been solved iteratively. The method and the results are given in detail in Fang et al. (1992). As an illustration, Figure 2 gives $\Delta\lambda_r - \Delta\lambda_b$ versus $(I_r - I_b)/I_c$, which were measured on the theoretical Non-LTE profiles of CaII K line, corresponding to different velocity patterns for the F_2 model.

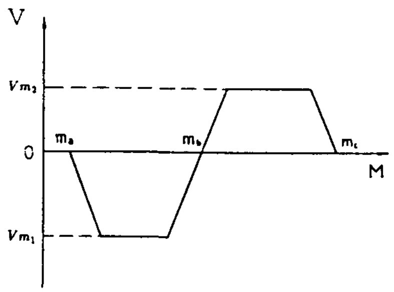

Fig. 1. Terraced velocity distribution around the temperature minimum region (TMR).

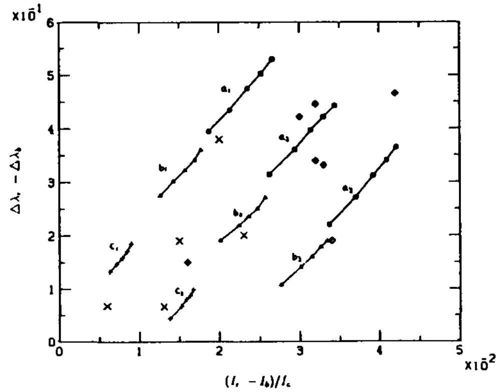

Fig. 2. Calculated $\Delta\lambda_r - \Delta\lambda_b$ versus $(I_r - I_b)/I_c$ for the F_2 flare model. See text in detail.

In Figure 2, each line consists of five points, corresponding to calculations with different plasma-moving widths (w) in the atmosphere. The TMR is chosen as the position of m_b. A region with a width of 260 km below the TMR is taken as w_2 when $V_{m_2} \neq 0$, and the width (w_1) above the TMR is taken to be 720, 660, 590, 520 and 430 km, respectively, for the points from the upper-right corner to the lower-left corner of each line. The combination of V_{m_1} and V_{m_2}, in the series name, is denoted as $a_1, a_2, \ldots, c_2$ and is listed in Table I. The observed asymmetries for the 12 flares are also plotted in Figure 2 with a symbol of $\times$ for small flares ($R_{max} \leq 1.1$) and that of $\diamond$ for large flares ($R_{max} > 1.1$). The results for the F_1 model are qualitatively similar to that for the F_2 model, though the difference between them is considerable.

Thus, the red asymmetry of the CaII K line can be explained by the downward moving plasma in the low chromosphere with a typical velocity of 10–30 km s^{-1}. For some flares with strong asymmetry at the K_1 positions, it is plausible that there is an upward-moving plasma below the TMR with a typical velocity of 10 km s^{-1}.

TABLE I Values of V_{m_1} and V_{m_2}, in the Series of Model Calculations

Series	F1 V_{m_1}(km s^{-1})	Model V_{m_2}(km s^{-1})	F2 V_{m_1}(km s^{-1})	Model V_{m_2}(km s^{-1})
a_1	-30	0	-30	0
a_2	-30	10	-30	10
a_3	-30	20	-30	20
b_1	-20	0	-20	0
b_2	-20	10	-20	10
b_3	...	...	-20	20
c_1	...	...	-10	0
c_2	...	...	-10	10

This explanation is supported by the observations of flare metallic lines. The observations indicate that during the impulsive phase of flares, some strong metallic lines also show red asymmetry, while the centers of metallic lines have generally no Doppler shift or only weak blue shift (Ding 1992). The later fact can be naturally understood by the contract-like motion around TMR, because the metallic lines are formed in the low atmosphere.

REFERENCES

Canfield, R.C., and Gunkler, T.A. 1985, *Ap. J.*, **288**, 353.

Ding, M.D. 1992 , Thesis.

Fang, C., Gan, W.Q., Huang, Y.R., and Hu, J. 1986, in *The Lower Atmosphere of Solar Flares*, ed. D. Neidig (NSO, Sunspot, NM), p.117.

Fang, C., Hiei, E., Yin, S.Y., and Gan, W.Q. 1992, *P.A.S.J.*, **44**, 63.

Gan, W.Q., and Fang, C. 1987, *Solar Phys*, **107**, 311.

Ichimoto, K., and Kurokawa, H. 1984, *Solar Phys*, **93**, 105.

Machado, M.E., Avrett, E.H., Vernazza, J.E., and Notes, R.W. 1980, *Ap. J.*, **242**, 336.