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Derivation of the downward velocity of the flaring region of 26 June 1999

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Abstract In the present study, three methods have been used to compute the downward velocity of the flare plasma of the solar flare on June 26, 1999. The first method is used to determine the plasma velocity of the studied flare from the Hα line asymmetries by using the asymmetry method developed by Edward (2009). The second one is to obtain the downward velocity of the flare plasma from the far wings of the excess profiles by the bisector method. This method was employed by; for example, Ichimoto and Kurokawa (1984), Falchi et al. (1992), and Ding et al. (1995). The third method is the modified cloud model which is described by Liu and Ding (2001a,b), Gu and Ding (2002), Semeida et al. (2004) and Berlicki (2007).
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1. Introduction

Different models and methods have been proposed by different authors to detect and measure the macroscopic downward velocity through the analyses of the line profiles of different line spectra of solar flares. But the obtained results are far from being conclusive even in the case of the photosphere and the diagnostics of downward velocity. Spectral lines in solar flares typically indicate the profile asymmetry. This phenomenon contains information on the downward velocity present in different depths of the solar atmosphere affected by abrupt heating or various non-thermal flare processes. As the spectral lines of various chemical elements originate at different heights of the solar atmosphere, they can be used for diagnostic of the spatial distribution and time evolution of downward velocity in the flaring atmosphere.

Usually the red asymmetry is interpreted as a consequence of downward motions of cool and dense plasma which is known as *chromospheric condensation* with downward velocities of the order of tens km/s. Origin of these motions is most probably due to a fast heating of upper chromospheric layers which is caused by particle beams during the impulsive phase

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of a flare. A small but long lasting blue shifts in the Hα line core in a two-ribbon flare have been observed by Schmieder et al. (1987) who interpreted them as a consequence of upward mass motions with upward velocities up to 10 km/s. They called this *a gentle evaporation*. During the impulsive phase of a flare the energy is transported by beam of non-thermal particles which proceed from the corona to the chromosphere and cause an explosive heating. However, if the energy flux transferred by these particles is low, gentle evaporation takes place due to other heating and dynamical processes. One can assume that it arises after the primary energy release and after thermalization of electron beams. These physical conditions prevail during the gradual phase of a flare (Berlicki et al., 2005). Asymmetry of a spectral line profile arises from motions of a flaring atmosphere. Therefore, detection of asymmetries can be used as a tool for studying such motions and for testing of different flare models.

Most extensive data available is for Hα line. Strong asymmetries are mainly red but also blue have been detected during the impulsive phase of a flare; Ichimoto and Kurokawa (1984), Canfield et al. (1990a,b), Heinzel et al. (1994) and others.

2. Overview

One of the most evident signatures in Hα lines of solar flares is the red asymmetry of the profiles. Such line profile asymmetries were discovered and recorded for the first time by Waldmeier (1941). The emission width in the red wing of the Hα spectral line in flares was broader than the blue wing. A statistical study of 244 Hα spectra of 92 flares by Svestka et al. (1962) revealed that, 80% of flares have at least one region with red asymmetry, 32% with blue asymmetry and only 5% of flares however show exclusive blue asymmetry. On other hand, it has long been known that an expanding atmosphere would sometimes cause a red asymmetry of spectral lines as shown by Hummer and Rybicki (1968). Severny (1968) found similar results with limb flares with the exception of more than 14% that showed exclusive blue asymmetry. Athay (1970) measured the velocities for the Hα line and got that, these velocities are very often greater than the actual velocity and very often less than the actual velocity.

In 1976 Svestka concluded that the red asymmetry is a phenomenon observed in most flares and it has been interpreted as being due to Doppler shifts from vertical mass motions in the flare region and summarized that the highest velocity is found for hydrogen (∼100 km/s) (Svestka, 1976). Smaller velocities are deduced from helium and Ca II, H and K lines (a few tens of km/s), while the velocity in metals is close to 10 km/s. The time scale of the impulsive phase is of the order of seconds. In 1993, Shoji and Kurokawa successfully obtained the impulsive phase spectra in five wavelength regions simultaneously with sufficiently high temporal resolution (Shoji and Kurokawa, 1993). Studies of photometric Hα profiles of 24 flares of class 1 (larger flares) recorded with a multi-slit spectrograph have been done by Schoolman and Ganz (1981). All events studied reveal significant shifts toward longer wavelengths and most of those with unequal emission peak intensities in the self-reversal profile are also red dominant with only a few exceptions where the blue peaks are slightly brighter.

Frances Tang (1983) studied the Hα asymmetry of the solar flares and found that, 92% of the flares studied show red asymmetry, 5% shows blue asymmetry while 3% lack of the obvious red asymmetry during some stages of their flare development.

In some cases, the blue asymmetry of Hα line profiles may also appear and persist for rather long time as shown by Heinzel et al. (1994). Fisher et al. (1985) found that, the origin of the downflows could be related to the chromospheric condensations which are believed to result from impulsive heating at the top of the chromospheres and accompany the formation of the chromospheric evaporation. Wulser (1987) stated a quantitative value of the red asymmetry by measuring the effective line width separately for the red and blue wings then subtracting the first from the later. De la Beaujardiere et al. (1992) have calculated the temporal evolution of the downward velocities and found that the slowing-down time is about four times longer than the value predicted in a theoretical model of Fisher (1989). Some detailed computations have shown a complicated correlation between the velocity field and the line asymmetry. Gan et al. (1993) showed that the downward-moving chromospheric condensation can not only explain the Hα red asymmetry, but also the blue asymmetry, if one changes the parameters of the condensation. Heinzel et al. (1994) also found that a downward velocity in the transition region and upper chromospheres would produce a blue asymmetry of the Hα line. Asymmetric behavior of Hα foot point emission during the early impulsive phase of a flare studied by Qiu et al. (2001), shows that the asymmetric Hα foot point emission cannot be explained by the magnetic mirroring effect in which strong field foot points show lower precipitation rates. Gu and Ding (2002) found that the velocity distribution shows that, the red shift and blue shift velocities lie respectively in the northern and southern parts of the flare and that the maximum red-shift velocity is 35 km/s and the biggest blue-shift velocity is 40 km/s for Hα. Berlicki (2007) showed that the downward motion increases at the onset of a flare to its maximum velocity of 40–100 km/s shortly before the impulsive peak of microwave emission. Generally, it is difficult to infer the exact mass motion velocities of an optically thick line, especially in the case of the large velocity gradient. A relatively accurate method is to make detailed computation of the line profile from the atmosphere with the existence of various velocity fields.

3. Data used

In the present study, the Hα spectra of a weak flare on June 26, 1999 was taken by Ondrejov multichannel flare spectrograph and used during the observation time interval from 07:23:33 UT to 08:05:51 UT in the active region NOAA 8598 located at N20 E09 as shown in Fig. 1. This Hα spectrum was the only available spectra for study. According to Solar Geophysical Data, this flare began at 07:18E UT, ended at 08:19:09 D, reaching its maximum at 07:23 UT, with Hα importance SF and according to GOES, it had soft X-ray class C 7.0. The observed frames spectra involved Hydrogen Balmer lines H_α and H_β and the infrared strongest Calcium triplet line 8542 Å. The observed frame spectra have been analyzed and stored in digital form. An example is shown in Fig. 2. The registered observations of this flare are about 42 min from its beginning to its end. The three emission spectral lines (Hα, H_β and the infrared strongest Calcium triplet line 8542 Å) appeared clear. This flare is unstable with complicated morphology with good seeing and good features.

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