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Semiempirical photospheric models of a solar flare on May 28, 2012

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Abstract

The variation of the photosphere physical state during the decay phase of SF/B6.8-class solar flare on May 28, 2012 in active region NOAA 11490 is studied.

We used the data of the spectropolarimetric observations with the French–Italian solar telescope THEMIS (Tenerife, Spain). Semiempirical model atmospheres are derived from the inversion with SIR (Stokes Inversion based on Response functions) code. The inversion was based on Stokes profiles of six photospheric lines. Each model atmosphere has a two-component structure: a magnetic flux tube and non-magnetic surroundings. The Harvard Smithsonian Reference Atmosphere (HSRA) has been adopted for the surroundings. The macroturbulent velocity and the filling factor were assumed to be constant with the depth. The optical depth dependences of the temperature, magnetic field strength, and line-of-sight velocity are obtained from inversion.

According to the received model atmospheres, the parameters of the magnetic field and the thermodynamical parameters changed during the decay phase of the flare. The model atmospheres showed that the photosphere remained in a disturbed state during observations after the maximum of the flare. There are temporal changes in the temperature and the magnetic field strength optical depth dependences. The temperature enhancement in the upper photospheric layers is found in the flaring atmospheres relative to the quiet-Sun model. The downflows are found in the low and upper photosphere at the decay phase of the flare.

Keywords: Solar flare; Magnetic field; LOS velocity; Temperature; Photosphere

1. Introduction

It is now widely accepted that solar flares are a result of the magnetic reconnection. Emerging magnetic flux can interact with overlying large-scale magnetic fields, and reconnection leads to eruptive release of enormous energy stored in the current sheets. The released energy results in a heating of the plasma and acceleration of charged particles. The energy input in the lower atmosphere triggers chromospheric evaporation and condensations. Cauzzi et al. (1995, 1996), Falchi and Mauas (2002) revealed strong changes of the chromospheric thermodynamical parameters during small flares after the hard X-ray spikes. These changes were caused by the electron beam. Brosius and Holman (2009) suggested the possibility of a direct heating by magnetic reconnection in the chromosphere of the microflares.

All levels of the solar atmosphere are perturbed during the flares. The response to a thermal energy deposition takes place in the photospheric layers as well. The knowledge of the physical conditions in the photosphere during flare processes is essential for the understanding of the flare nature and role of the magnetic field in it. The variations of the photospheric line profiles, their asymmetries and shifts are revealed in solar flares (e.g., Abramenko and Baranovsky, 2004; Cauzzi et al., 1996; Kleint, 2012;

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Kondrashova and Pasechnik, 1997; Kondrashova and Rudnikova, 2003; Kurochka et al., 2008). The physical state of the photosphere in the solar flares at the decay phase was studied by Abramenko and Baranovsky (2004), Alikaeva and Kondrashova (2006), Andriets et al. (2014), Chornogor and Alikaeva (2001), Gan and Fang (1987), Kondrashova (2011), Kurochka et al. (2008). Semi-empirical model atmospheres obtained in these works show the variations of all physical parameters during the decay phase. In most cases the temperature in these models has some inhomogeneities with height. The layers with increased temperature were found in the middle and the upper photosphere in relation to undisturbed photosphere. The temporal sequence of the thermodynamical parameter variations indicates that the flaring disturbances propagate out from the magnetic reconnection and the energy release region in the upper solar atmosphere and penetrate deeply into the photosphere down to its base (e.g., Alikaeva et al., 1995; Alikaeva and Kondrashova, 2006; Chornogor and Alikaeva, 2001, 2002; Kondrashova, 2013).

The evolution of the photospheric magnetic field during the flares was studied in a number of the works (e.g., Kosovichev and Zharkova, 1999, 2001; Petrie and Sudol, 2010; Sudol and Harvey, 2005; Tanaka, 1978; Wang, 1992). The authors of these papers reported about rapid significant changes in the photospheric magnetic field at the beginning of the flares. Kosovichev and Zharkova (1999, 2001) found a continuous change in the longitudinal magnetic field during the X1-class flare on 1998 May 2 and the "Bastille Day Flare". Meunier and Kosovichev (2003) have analyzed photospheric flows and magnetic fields in a flaring active region NOAA 9236 before and after a X4.0 flare of November 26, 2000. They found strong permanent changes of the longitudinal magnetic flux, associated with the flare. Sudol and Harvey (2005), Petrie and Sudol (2010) revealed significant longitudinal magnetic field changes during X-class flares after their start. These results are found for the large flares. The evolution of the photospheric magnetic field during small flares is not well studied.

Spectropolarimetric investigations allow us to get more detailed information about the changes of the thermodynamical conditions and the magnetic field. The model atmospheres constructed using spectropolarimetric data (Andriets et al., 2014; Kondrashova, 2013) show significant variations of the magnetic field strength during the flares. SIR (Stokes Inversion based on Response functions) code (Ruiz Cobo and del Toro Iniesta, 1992) was used for the inversion in these works. We have obtained that during the flare all physical parameters including the magnetic field strength show rather strong variations at the photospheric level. In particular, the value of the longitudinal magnetic field strength shows the maximum at the peak of the flare.

However, the physical processes in the photosphere at the decay phase of the flares are not yet well understood. Some features of these processes have not yet been clarified. The aim of our work is to investigate the variations of the magnetic fields and the thermodynamic parameters with the help of the multi-line spectropolarimetric observation data. In present paper physical state of the photosphere at the decay phase of the SF/B6.8 flare on May 28, 2012 in active region NOAA 11490 has been analyzed. We used the data of the spectropolarimetric observations with the French–Italian solar telescope THEMIS (Heliographic Telescope for the Study of the Magnetism and Instabilities on the Sun) at the Teide Observatory (Tenerife, Spain) in the multi-line spectropolarimetric mode (Ceppatelli, 2004; Lopez Ariste et al., 2000; Paletou and Molodij, 2001). The data were obtained with a space resolution of about 1″. Semi-empirical model atmospheres for the decay phase of the flare are derived from the inversion of the Stokes spectra with the help of SIR code.

2. Observations

The active region (AR) NOAA 11490 (β-configuration) appeared on May 24, 2012. Spot group was bipolar. In the course of the AR evolution new magnetic fluxes were emerging. AR was located at 12° S, 17° E at the day of our observations on May 28, 2012. According to the Space Weather Prediction Center (SWPC) data, the H_α SF class flare occurred at 14:09 UT, the peak was at 14:13 UT and the end at 14:36 UT. GOES (Geostationary Operational Environmental Satellite) recorded B6.8-class X-ray burst which started at 14:09 UT and reached its maximum at 14:19 UT. Its end was at 14:36 UT.

Fig. 1 presents the EUV image of the flare under consideration from the Solar Dynamics Observatory (SDO)/ Atmospheric and Imaging Assembly (AIA) at 131 Å and GOES X-ray flux.

The spectropolarimetric observations were carried out with the French-Italian solar telescope THEMIS. The seeing conditions were good during the time of our observations. Spatial resolution was below 1″. The pixel sampling was 0.2″. The slit was located near the center of the AR NOAA 11490, just at the place of polarity inversion (at the heliocentric angle $\mu = 0.86$). Cameras recorded simultaneously the Stokes parameters I, Q, U, and V for the spectral intervals 6328–6333 Å, 6300–6305 Å. We use the time series of the spectra from 14:16 UT till 14:25 UT. A fixed-slit time series includes 300 spectral images. The time interval between spectra was 2.84 s. We have selected seven spectra of the best quality for study. The spectropolarimetric data were corrected for instrumental effects and telescope polarization by means of standard reduction procedure (Lopez Ariste et al., 2000). The rms noise level of the Stokes parameters in the continuum was about 10^{-3} in the units of continuum intensity. The H_α spectrum obtained at 14:18:31 UT is shown in Fig. 2. The field of view of THEMIS in polarimetric configuration is divided into three parts, each of them about 16 arcsec long. The horizontal white lines denote the intervals between them. The flare is in the central part of the spectrum. This work