Weak flares on M-dwarfs

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Abstract We have investigated the physics of flares in M-dwarfs by means of optical/X-ray observations and modeling. The great efficiency of current optical spectrographs and detectors has allowed us to detect and analyse a great number of non white-light flares with intermediate spectral resolution and high temporal resolution. Although this kind of flares is the most typical on the Sun, few such events have been so far recorded on stars. We have obtained the physical parameters of the chromospheric flaring plasma (electron temperature, electron density, optical depth and temperature of the underlying source) by using a model that minimizes the difference between the observed Balmer decrements and the calculated ones, which result from solving the radiative transfer equation. On the other hand, the great sensitivity, wide energy range, high energy resolution and continuous time coverage of the EPIC detectors (on-board the XMM-Newton satellite) have enabled us to study both the effect of weak flares on the corona of active stars and the spatial properties of coronal flaring loops. The results are consistent with interpreting stellar flares as scaled-up versions of solar flares and show multiple evidence for flares being an important heating agent of the outer atmospheric stellar layers.

Key words: Stars: activity – Stars: chromospheres – Stars: coronae – Stars: flare – Stars: late-type

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1 Introduction

Stellar flares usually affect plasma at very different heights in a star's atmosphere. While X-ray observations are needed to study coronal properties of flares, optical and ultraviolet ranges are used to investigate their effects in chromospheres. In this work we analyse optical and X-ray observations to deepen in the knowledge of activity and flaring plasmas throughout the atmosphere of M-dwarfs.

2 Optical studies

2.1 Characterizing the chromospheric activity of M-dwarfs

We analysed the late Ke- and Me-dwarfs (a total of 10 objects) included in our high-resolution spectroscopic survey of 144 late-type stars (spectral types from F to M, see [5]) classified as possible members of young stellar kinematic groups [6]. In this section, we summarize the obtained results. Some figures and further details about this work can be found at [1].

Despite the unknown inclination of the rotation axis for almost all the stars in the survey, flare M-dwarfs seem to follow the well-known age-activity-rotation relationship when they are observed in the Ca II λ8542 Å line, while their Hα emission appears to be independent of the rotational velocity.

Clear relationships are also observed between the chromospheric flux of different emission lines. Although the flare M-dwarfs generally follow the tendencies observed for the rest of stars in the spectroscopic survey, different results are found for the relationships between the Balmer series and Ca II lines. The flare M-dwarfs show an excess in the chromospheric emission of the Balmer lines when they are compared to the rest of stars with equal chromospheric emission in the Ca II lines. We suggest that these differences are due to microflaring activity, although further investigations are still needed.

At present, we are testing these results and improving their physical interpretation by using a larger sample of late Ke- and Me-dwarfs.

2.2 Time analysis of flares detected on the chromosphere of M-dwarfs

We carried out a high temporal resolution spectroscopic monitoring of the flare star AD Leo (M3Ve). During 4 nights, more than 450 optical spectra were taken using the Isaac Newton Telescope (INT), the Intermediate Dispersion Spectrograph (IDS) and the R1200B grating. A large number of short and weak flares was detected (frequency $>$ 0.7 flares/hour). This is consistent with a scenario in which flares are a very important heating agent of stellar coronae. The behaviour of different chromospheric lines (Balmer series from Hα to H_{11} and Ca II H & K lines) was studied in detail. The detected flares are non white-light flares. It is interesting to note that, although most solar flares are of this kind, very few such events were previously observed in stars.

We estimated the physical parameters of the flaring plasma – electron temperature (T_e), electron density (N_e), optical depth in the Lyα line ($\tau_{Ly\alpha}$) and temperature of the underlying source (T_{us}) – by using the procedure developed by Jevremović et al. [4]. This method minimizes the difference between the observed Balmer decrements and the calculated ones, which result from solving the radiative transfer equation. The obtained physical parameters [N_e = (6 – 20) $\times$ 10^{13} cm^{-3}; T_e = (12 – 24) $\times$ 10^3 K; T_{us} = (8 – 13.5) $\times$ 10^3 K] are consistent with previous values derived for stellar flares. In particular, the flaring area (less than 2.3% of the stellar surface) is comparable with the size inferred for other solar and stellar flares.

From the relationships observed between the physical parameters and the surface, duration, maximum flux and energy released during the detected flares, we inferred that:

- The flare duration could be related to the loop length, as in X-rays.
- The temperature of the underlying source could be related to the depth of the layer reached by the accelerated particles.
- Larger released energies may imply larger depths, but not necessarily a higher temperature of the underlying source.

We encourage the reader to see figures and further details about the work given in this section at [2].

3 X-ray studies: time analysis of flares detected on the corona of M-dwarfs

We performed time-resolved X-ray spectroscopy of two flares weaker than those typically analysed. These flares were observed on the very active BY Dra-type binary star CC Eri (K7.5Ve + M3.5Ve; $P_{orb} \approx 1.56$ days) using the EPIC-PN CCD camera, on-board the XMM-Newton satellite.

The analysed flares lasted $\sim$ 3.4 and 7.1 ks, with flux increases of factors 1.5 – 1.9. Spectral analysis shows that all the regions in the light curve, including the flare segments, are well-described by a $2T$ – APEC[1] model ($Z/Z_\odot$ = 0.3 $\pm$ 0.1) with variable emission measures but, surprisingly, constant temperatures (values of 3, 10 and 22 MK). This result resembles that found by Reale et al. [8] when analysing the Sun as an X-ray flaring star. They obtained $EM(T)$ distributions with variable height, but invariably peaked and centred around the same temperature, independently of the flare phase.

[1] APEC: Astrophysical Plasma Emission Code

We have inferred the size of the flaring loops by using Eq. 1 (see [7]), which has into account the effect of possible heating during the decay:

$$L = \frac{\tau_{\rm D}\sqrt{T_{\rm max}}}{3.7\times 10^{-4} F(\xi)}\ , \qquad (1)$$

where L is the loop half-length (cm), $\tau_{\rm D}$ the e-folding decay time (s), $T_{\rm max}$ the loop maximum temperature (K), and $F(\xi)$ a non-dimensional factor (larger than one) which accounts for the effect of possible heating during the decay. The slope in the density-temperature diagram (ξ) found for the decay of the detected flares (0.18 ± 0.27 and 0.45 ± 0.08) indicates the presence of significant heating during this phase for both events. Both flares occurred in arcades made of a few tens of similar coronal loops with $L \approx 7 \times 10^9$ and 14×10^9 cm, respectively. These flaring loops are much smaller than the distance between the stellar surfaces in the binary system, and even smaller than the radius of each one of the stars ($0.1 \leq L/R_* \leq 0.4$). The obtained results are consistent with the following ideas:

- The whole X-ray light curve of CC Eri could be the result of a superposition of multiple low-energy flares.
- Stellar flares can be scaled-up versions of solar flares.

For further details about the work summarized in this section, see [3].

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