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High Temporal Resolution Spectra of Flare Stars

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Abstract. The results of a high temporal resolution spectroscopic monitoring of the UV Cet type flare stars AD Leo and V1054 Oph are reported. Intermediate resolution optical spectra of these stars were taken using the IDS spectrograph of the 2.5 m Isaac Newton Telescope (INT) of El Roque de los Muchachos Observatory (Spain) during 4 nights (2-5 April 2001). We have obtained high temporal resolution by taking series of spectra with short exposure times (15-300 sec) separated only by the CCD readout time (∼60 sec). The great number of spectra observed each night has allowed us to analyse the temporal evolution of the emission lines and to identify several flares of different intensity and duration.

1. Introduction

The "clasical" flare stars are the UV Ceti stars, which are main sequence (MS) stars with spectral type later than ∼K5Ve. Their rapid rotation, in combination with a deep convection zone, generates efficient dynamo magnetic activity (García-Alvarez 2000). Flares of this kind of stars are indeed the most similar to the solar ones. Both AD Leo and V1054 Oph are UV Cet type stars. AD Leo (Gl 388) has been classified as a dM3.5Ve star (Kunkel 1975) with a photometric period of 2.7±0.5 days (Spiesman & Hawley 1986). V1054 Oph (Gl 644, Wolf 630AB) is a close visual binary (Kuiper 1934) with an angular separation of 0.218″ and a short orbital period (∼1.714 years) (Voûte 1946) in which the B component is a spectroscopic binary with a period of ∼2.966 days (Joy 1947; Weis 1982; Mazeh et al. 2001). The V1054 Oph system is classified as dM3.5Ve as a whole (Joy & Abt 1974). AD Leo and V1054 Oph show very strong activity and produce energetic flares (Pettersen et al. 1984a, b). Due to their proximity to the Sun (4.69±0.09 pc in the case of AD Leo and 5.74±0.13 pc in the case of V1054 Oph), these stars are relatively bright ($V_{\rm AD\ Leo}$≈9.43, $V_{\rm V1054\ Oph}$≈9.04) and their flares can be easily observed.

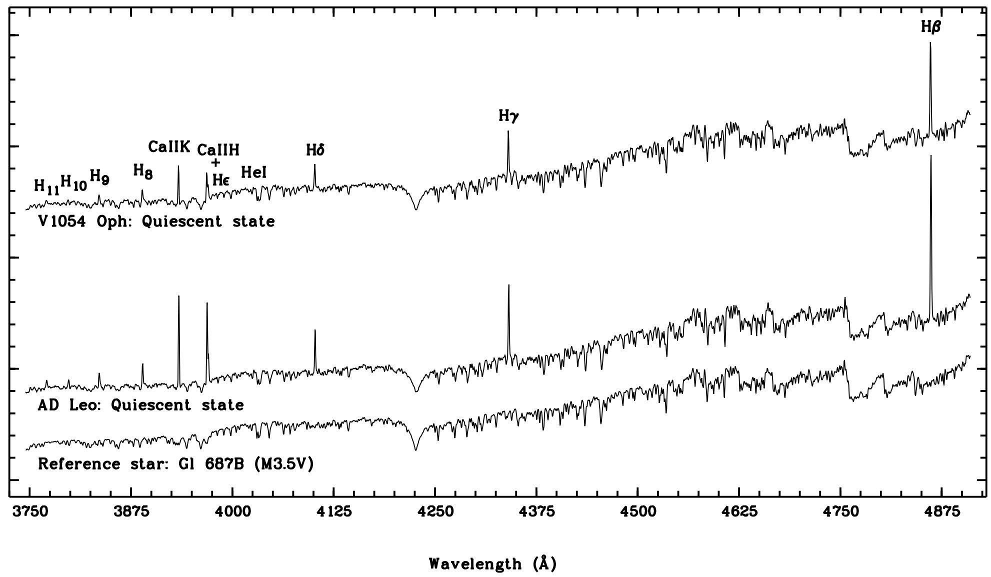

Figure 1. Quiescent spectrum of AD Leo and V1054 Oph, both compared with the spectrum of the reference star Gl 687B (M3.5V).

2. Observations

The observations were done during the MUlti-SIte COntinuous Spectroscopy (MUSICOS) 2001 campaign. The 2.5 m Isaac Newton Telescope (INT) was used at El Roque de Los Muchachos Observatory (La Palma, Spain) with the Intermediate Dispersion Spectrograph (IDS) and a 2148x4200 EEV10a CCD detector. IDS worked with the dispersion grating R1200B, covering the wavelength range 3560-5170 Å (which includes the Balmer lines from H_β to H_{11} as well as the Ca II H & K and He I 4026 Å lines), being the reciprocal dispersion 0.48 Å/pixel and the spectral resolution (FWHM) 1.22 Å. The spectral lines of the three components of V1054 Oph are not resolved with this spectral resolution. All the spectra were calibrated by using Cu-Ar arcs. Series of spectra of AD Leo and V1054 Oph, separated only by the CCD readout time (less than 60 sec), are available each night. The exposure times ranged from 15 to 300 sec in the case of AD Leo (S/N ≈ 27–89 in the region of the H_β line) and from 15 to 240 sec in the case of V1054 Oph (S/N ≈ 34–112). A total of 459 spectra of AD Leo and 233 of V1054 Oph were obtained.

Figure 1 shows the observed spectra of AD Leo and V1054 Oph in their quiescent states. The observed spectrum of the reference star Gl 687B (M3.5V) is also plotted for comparison. These two stars present strong emission lines, even in their quiescent states.

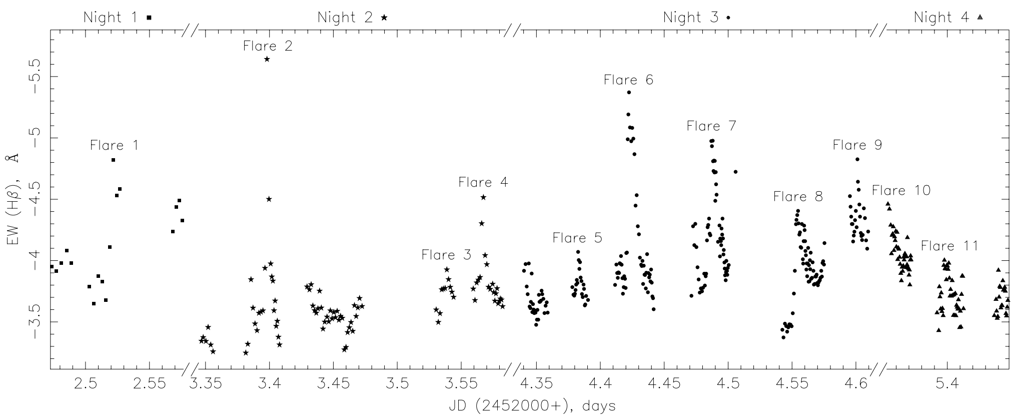

Figure 2. EW(H_β) of AD Leo versus time (JD) for every night.

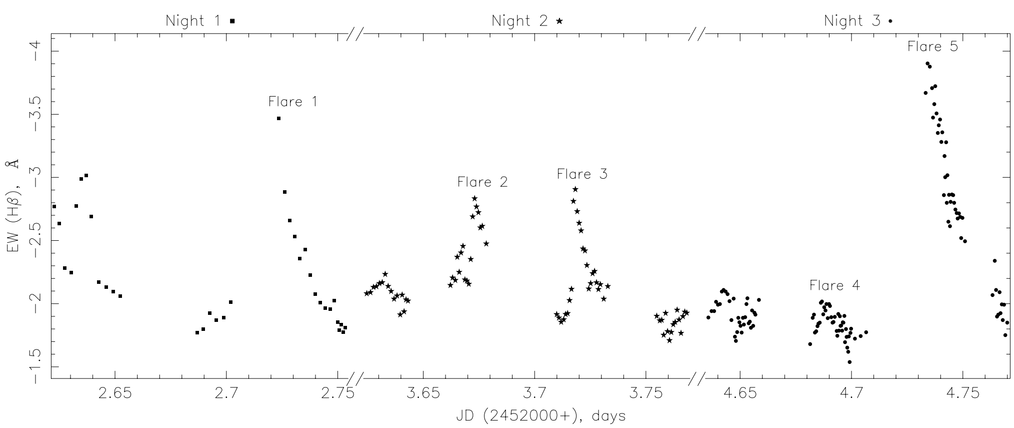

Figure 3. EW(H_β) of V1054 Oph versus time (JD) for every night.

3. Results

The temporal evolution of the equivalent width (EW) of the Hβ line has been plotted in Figures 2 and 3 for AD Leo and V1054 Oph, respectively. The relative error in EW(Hβ) ranges from 9 to 20 % in the AD Leo values and from 11 to 36 % in the V1054 Oph ones. The same flares have been also detected using the rest of the chromospheric emission lines given in Figure 1 (Balmer lines from Hδ to H_{11}, the CaII H & K lines and the 4026 Å HeI line). Several flares of different intensity and duration can be observed. The high temporal frequency observed in flares is in fact specially remarkable. Flares are also believed to be one of the mechanisms responsible of coronal heating of active stars. In addition to the flares, small changes at shorter time scales are also observed in the emission lines. The detected flares last from 14±1 to 31±3 min in the case of AD Leo and from 21±2 to 96±6 min in V1054 Oph. The EW(H_β) changes by a factor of ∼1.3 in Flare 3 up to ∼1.7 in Flare 2 of AD Leo and by a factor of ∼1.3 in Flare 4 up to ∼2.3 in Flare 5 of V1054 Oph.

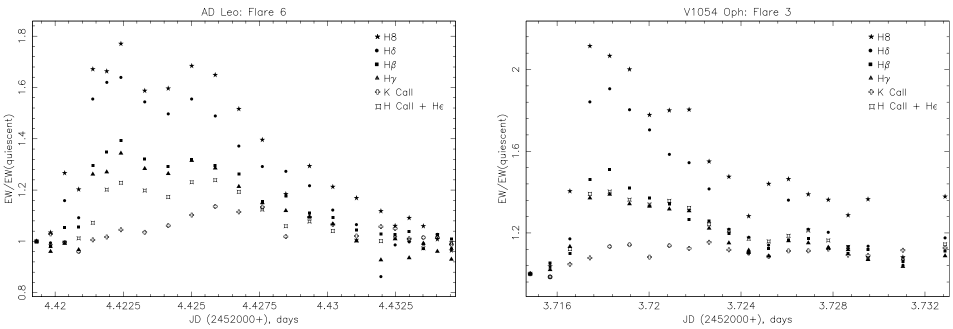

Figure 4. EW ratio (relative to the quiescent state) of different lines during the best monitored flares in our observations: Flare 6 of AD Leo (left) and Flare 3 of V1054 Oph (right)

For the best monitored flare of each star, Figure 4 shows the temporal evolution of the chromospheric emission lines located in the continuum regions with better signal to noise ratio (SNR) (CaII K, H_ϵ+CaII H, H_β, H_γ, H_δ and H_8). The relative error in this quantity during these two flares is $\sim 15\%$ in the Ca II lines and $\sim 25\%$ in the Balmer ones. It can be seen that the temporal behaviour of Balmer lines is similar: a sadden increase takes place during the impulsive phase, reaching the maximum at the same time and, finally, a gradual decay. The evolution of CaII H & K is quite different from the one of Balmer lines: the maximum EW ratio relative to the quiescent state is smaller, the increase during the impulsive phase is slower (as the decrease in the gradual decay) and the maximum intensity is reached later than the Hydrogen lines. It can be also observed that the increase of Balmer lines is higher at shorter wavelengths, even though the Hβ and Hγ changes are quite similar. These differences on the rise of intensity become higher in the flare maximums.

The Hβ line profile evolution is given in Figure 5. Balmer lines present a red-asymmetry even in the quiescent state of each star. The Balmer lines experiment a broadening during flares, and the blue and red wings of each line become wider, reaching the maximum width in the flare maximum. But, although the emission in the two wings increase during the flares, the red-asymmetry becomes greater during these process. The line broadening and asymmetry can be attributed to plasma turbulence and mass motions during the flare events, such as chromospheric downward condensations and chromospheric evaporation.

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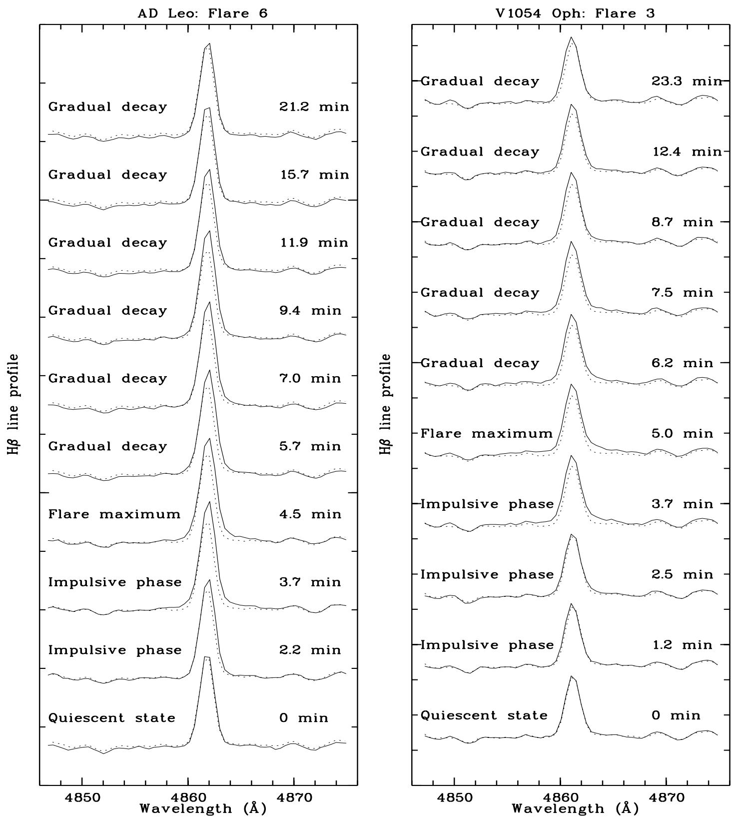

Figure 5. Evolution of the H_β line profile (solid line) during the best monitored flares in our observations (Flare 6 of AD Leo (left) and Flare 3 of V1054 Oph (right)), compared with the quiescent state (dotted line) of the respective star.

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