Abstract

We present the results of a high temporal resolution spectroscopic monitoring of the flare stars AD Leo and V1054 Oph. Intermediate resolution spectra, including the Balmer lines from Hα to Hβ, and the Ca II H & K lines, have been taken using the IDS spectrograph of the 2.5 m Isaac Newton Telescope (INT) (La Palma) during 4 nights (25-26 April 2001). We have obtained high temporal resolution by taking spectra with exposure times as short as 25 to 60 sec. (SN 10 to 65) separated only by the CCD readout time (60 sec). The great number of spectra taken during each night, with this high temporal resolution has allowed us to analyze the temporal evolution of the emission lines and identify several flares of different intensity and duration each night. For the more prominent flares we have studied in detail the behavior of the different chromospheric lines during the phases (pre-flare, impulsive, gradual decay) and estimated the physical parameters of the flaring plasma. The flares found in these observations last about 30 min. During these flares, the equivalent widths of the lines change in a factor up to 2.3 and broaden and asymmetric (blue, or red-shifted) line wings are observed as well.

AD Leo

Observed blue and red spectra of AD Leo and V1054 Oph in its quiescent state and in the maximum phase of a flare. The observed spectrum of the inactive reference star Gl 687B (M5.5V) is plotted as a dotted line. The EW(Hα) changes in a factor of ~1.3 in the Flare 3 up to a factor of ~1.7 in the Flare 2. The duration of the observed flares ranges from ~22 to 43 minutes.

AD Leo

The EW(Hα) changes in a factor of ~1.3 in the Flare 3 up to a factor of ~1.7 in the Flare 2. The duration of the observed flares ranges from ~22 to 43 minutes.

AD Leo

Evolution of the equivalent width (EW) of the Hα line of AD Leo and V1054 Oph during the 4 first nights of observations. Several flares of different intensity can be observed. The same flares have also been detected using the rest of the emission lines from Hβ to Hα, including the Ca II H & K lines. In addition to the flares, we observed changes in the emission lines at shorter time scales that are also observed.

V1054 Oph

The EW(Hα) changes in a factor of ~1.3 in the Flare 4 up to a factor of ~1.7 in the Flare 5. The duration of the observed flares ranges from ~22 to 43 minutes.

V1054 Oph

Evolution of the equivalent width (EW) of the Hα line of AD Leo and V1054 Oph during the 4 first nights of observations. Several flares of different intensity can be observed. The same flares have also been detected using the rest of the emission lines from Hβ to Hα, including the Ca II H & K lines. In addition to the flares, we observed changes in the emission lines at shorter time scales that are also observed.

Behaviour of the chromospheric lines

Evolution of Balmer lines is similar: a sudden increase during the impulsive phase reaching a maximum in the same time and, finally, a gradual decay. Evolution of Ca II H & K lines in different flares. Hydrogen lines: the maximum of the line relative to the quiescent state is reached during the impulsive phase is slower (or the decrease in the gradual decay); and the maximum intensity is reached later than the Hydrogen lines. To see differences in the behaviour of different Hydrogen lines we have analysed the Balmer decrement (Dn/Dn+1) relative to the quiescent state at different times. We have found that the increase of Balmer lines is higher at shorter wavelengths. Differences on the rise of intensity becomes higher at the few first minutes of the flare. The behaviour of Hα is in agreement with the expected one, being the normalized decrement Δn = 1.0. This means that the change of these two lines (Hα and Hβ) is quite similar during all the phases of the flare.

AD Leo

Flare plasma parameters from Balmer Decrements

The Balmer decrement (normalized to Hα) of the Hα to Hβ lines at the maximum of the selected AD Leo flares have been used to determine the Balmer decrement. We have used the procedure to fit the Balmer decrement developed by Jerrentrup et al. (1998) and Garcia-Alvarez et al. (2002, 2003). The parameters obtained (see Table) are:

- electron temperature, T_e
- electron density, n_e
- optical depth in the Lyα line, τ_Hα
- equivalent width of the Hα line, EW(Hα)
- as well as the effective thickness of the slabs analyzed, δ

As well as the effective thickness of the slabs analyzed, δ

AD Leo

During the observed flares the Balmer lines experiment a broadening and a red-asymmetry that increases during the impulsive phase, becoming stronger at the flare maximum. The bisector of the emission line profiles changes in agreement with the expected one, being the line profiles at the maximum phase of a flare more symmetric than in the quiescent state. This line broadening and asymmetry can be attributed to plasma turbulence and mas motions (as chromospheric downflows and convections and chromospheric expansions) during the flare events.

V1054 Oph

Line broadening and Asymmetries

During the observed flares the Balmer lines experiment a broadening and a red-asymmetry that increases during the impulsive phase, becoming stronger at the flare maximum. The bisector of the emission line profiles changes in agreement with the expected one, being the line profiles at the maximum phase of a flare more symmetric than in the quiescent state. This line broadening and asymmetry can be attributed to plasma turbulence and mas motions (as chromospheric downflows and convections and chromospheric expansions) during the flare events.

V1054 Oph

Evolution of the equivalent width (EW) of the Hα line of AD Leo and V1054 Oph during the 4 first nights of observations. Several flares of different intensity can be observed. The same flares have also been detected using the rest of the emission lines from Hβ to Hα, including the Ca II H & K lines. In addition to the flares, we observed changes in the emission lines at shorter time scales that are also observed.

V1054 Oph

Evolution of Hα line profiles during the Flare 3 of V1054 Oph compared with the quiescent state. Note the line broadening and red-asymmetry.