High Resolution Spectra of Flare M-Dwarfs

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Abstract

Flare stars are generally observed using low resolution spectrographs in order to detect flares with a temporal resolution as higher as possible. However, high resolution spectra are needed to determine other properties of these stars as their kinematics (radial velocity), rotational velocity ($v\sin(i)$), age (Li I λ6708 Å line), and to study in detail the chromospheric emission line profiles.

In this contribution we analyse high resolution echelle spectra of several M-dwarfs classified as flare stars (UV Cet type). The wavelength range of the observations includes the optical chromospheric activity indicators Ca II H & K, Hε, He I 4026 Å, Hδ, Hγ, Hβ, Mg I b triplet, He I D_3, Na I D_2 & D_1, Hα and Ca II IR triplet, as well as other metallic lines that could be in emission during flares. We study all these spectral features, both the line emission and profile. The dependence on the age and rotation rate of the level of chromospheric activity in the quiescent state is also analysed.

Stellar Flares

Stellar flares are events in which a large amount of energy is released in a short interval of time, radiating at almost all frequencies in the electromagnetic spectrum. Flares are believed to result from the release of magnetic energy stored in the coronae through magnetic reconnection. In late Ke or Me dwarfs (UV Cet type stars) optical flares are a common phenomenon.

Observations

The UV Cet type flare stars that have been analysed in this work are the K7e- and Me-dwarfs (see Table. 1) included in our high resolution spectroscopic survey of 144 late-type stars (see Fig. 1) that are possible members of the young stellar kinematic groups groups IC 2391 supercluster (35-55 Myrs), Local Association or Pleiades moving group (20-150 Myrs), Castor moving group (200 Myrs), Ursa Major group (Sirius supercluster) (300 Myrs) and Hyades supercluster (600 Myrs) (see Montes et al. 2003 and López-Santiago et al. 2004a).

Fig. 1: Distribution of the sample of late-type stars included in the spectroscopic survey made by López-Santiago et al. (2004a). K7 and M stars are plotted in red. Flare dwarfs with spectral type later than K7e are marked with the symbol ★.

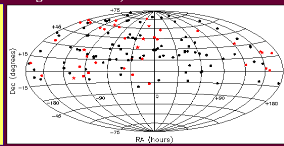


Table. 1: Stellar parameters of the flare K7- and M-dwarfs: spectral type (SpT), $v\sin(i)$ and photometric period (P_{phot}). The remark is -- for single stars, SB for spectroscopic binaries (singled lined (1) and double lined (2)) and T for triple star systems. The number of spectra taken of each star (N) and the ID of the observing run (see Table. 2) are also given. The exposure times of the spectra ranges from 18.3 to 30.0 min, except for the cases of V1054 Oph (16.7-25.0 min) and AD Leo (10.0-21.7 min).

✓ Stars marked with * have also been monitored with high temporal resolution (see Crespo-Chacón et al. 2004a, b, c and Montes et al. 2004).

✓ Parameters marked with ✎ have been determined from our spectra while the other ones have been taken from the literature.

Star	SpT	$v\sin(i)$ ✎ (km/s)	P_{phot} (days)	Remark	N ✎	Observing run (ID) ✎
FP Cnc	K7	11.35±0.13	--	--	2	5
HD 160934	K7	19.07±0.38	1.84	SB1	7	2, 5, 6
DK Leo*	K7-M0	7.68±0.70	7.98	--	2	5
GJ 9809	M0	8.05±0.82	--	--	1	4
GJ 856B	M1	17.7±1.9	--	--	1	4
CR Dra*	M1-M1.5	17.36±0.55	--	SB2	5	6
V1054 Oph*	M3-M3.5	2.9±2.0	--	T	10	2, 5
AD Leo*	M3.5	5.80±0.50	2.7	--	6	5, 1
V647 Her	M4	1.0±1.0	--	--	2	6
EV Lac	M4	2.01±0.53	4.38	--	11	2, 3, 4

Table. 2: Data of the observing runs. The telescope (column 3), instrument (column 4) and the CCD chip (column 5) is given for each observing run together with its date (column 2). The spectral range (column 6), number of orders (column 7), dispersion (column 8) and the resolution, FWHM, (column 9) are also given. Each observing run has been marked with a different identification number, ID, (column 1) for Table. 1.

ID	Date	Telescope	Instrument	CCD chip	Spectral range (Å)	# Orders	Dispersion (Å/pixel)	FWHM (Å)
1	11–22 01/2000	INT	MUSICOS	1024×1024 24μm TEK5	4430–10225	73	0.07–0.15	0.16–0.30
2	05–11 08/2000	INT	MUSICOS	1024×1024 24μm TEK5	4430–10225	73	0.07–0.15	0.16–0.30
3	21–24 09/2001	2.2m	FOCES	2048×2048 24μm Site#1d	3510–10700	112	0.04–0.13	0.08–0.35
4	10–11 10/2001	TNG	SARG	2(2048×4096) 13.5μm EEV 4280	4960–10110	62	0.02–0.04	0.08–0.17
5	22–25 04/2002	2.2m	FOCES	2048×2048 24μm Site#1d	3510–10700	112	0.04–0.13	0.08–0.35
6	01–06 07/2002	2.2m	FOCES	2048×2048 24μm Site#1d	3510–10700	112	0.04–0.13	0.08–0.35

2.2m ➔ 2.2m Telescope at German Spanish Astronomical Observatory (CAHA) (Almería, Spain); INT ➔ 2.5m Isaac Newton Telescope and TNG ➔ 3.5m Telescopio Nazionale Galileo, both at the Observatorio del Roque de los Muchachos (La Palma, Spain)

Estimation of Age

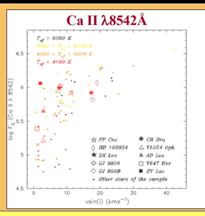
It is well-known that lithium abundance is an important diagnostic of age in late-type stars since it is rapidly destroyed by thermonuclear reactions in the stellar interior. However, in this case (M stars) lithium can be hidden by molecular bands or depleted. Nevertheless, almost all our flare stars have been classified as possible members of different young stellar kinematic groups (see López-Santiago et al. 2004a) using the galactic velocity components (U, V, W) that have been calculated for each star from its respective high resolution spectra. Therefore, we have estimated the age of each star as the age of its respective kinematic group (see Table. 3).

Star	Moving Group	Age (Myrs)
FP Cnc	Local Association	20-150
HD 160934	Local Association	20-150
DK Leo	Local Association	20-150
GJ 9809	Local Association	20-150
GJ 856B	Local Association	20-150
AD Leo	Castor	~200
EV Lac	Ursa Major	~300
V647 Her	Hyades	~600
CR Dra	—	—
V1054 Oph	—	—

Table. 3: Moving group possibly related with the star (column 2) and age of the star (column 3).

Activity-Rotation Relationship

The literature gives us the photometric period for only four of the flare stars of this work. Therefore we have chosen the parameter $v\sin(i)$ (projected rotational velocity), obtained from the high resolution spectra, to study the activity-rotation relationship. Without forgetting that we do not know the inclination of the rotation axis, it seems that, in general, the smaller is the effective temperature (T_{ef}) of the star, the slower is its rotation; and it also seems that the younger is the star, the higher is its rotational velocity (López-Santiago et al. 2004b). Fig. 2 and 3 show that our flare stars also show these tendencies. Besides, we can see that the level of activity of our flare stars seems to follow the general tendency of the other stars when we observe them in the Ca II λ8542Å line while the Hα emission of the chromosphere is independent of the rotational velocity.



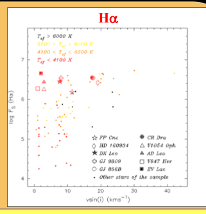


Fig. 2 and 3: log F_s(Ca II λ8542Å) and log F_s(Hα) vs. vsin(i) for the stars of the sample. Flare K7- and M-dwarfs have different symbols.

Flux-Flux relationships

The excess emission is the surface flux obtained by subtracting the contribution of the photosphere to the total surface flux emitted by the star. Fig. 4a to 7a show, for all the stars of the sample, the mean value of the excess emission of the Hα line vs. the mean value of the excess emission of other chromospheric lines (Ca II λ8542Å, Ca II K, Hβ and Hγ). Fig. 4b to 7b show the same but only for the flare stars of this work and Fig. 8 and 9 include the He I D_3 and Na I D_2 lines. The emission in Balmer series during flares grows more than in the Ca II lines. UV Cet type stars usually have short duration flares that happen very frequently (Crespo-Chacón 2004a, b, c; Montes et al. 2004). Therefore, more than a flare could have taken place during the exposure time of our observations (see Table. 1). In fact, it can be clearly noticed that our flare stars are out of the tendency followed by the other stars of the sample in Fig. 4 and 5, being higher the ratios F_s(Hα)/F_s(Ca II lines). These differences seem to be more noticeable for the flare stars with cooler spectral types. The Balmer flux-flux relationships (Fig. 6 and 7) seem to be linear for all the stars (slope > 0), including our flare dwarfs. The He I and Na I lines show the same behaviour (Fig. 8 and 9). The F_s for the Balmer series and for the He I and Na I lines is generally greater for the stars with later spectral types.

Fig. 4a: log F_s(Hα) vs. log F_s(Ca II λ8542Å) for the stars of the sample.

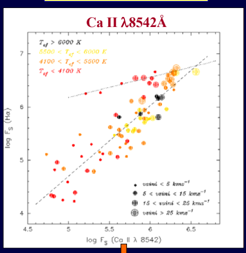


Fig. 5a: log F_s(Hα) vs. log F_s(Ca II K) for the stars of the sample.

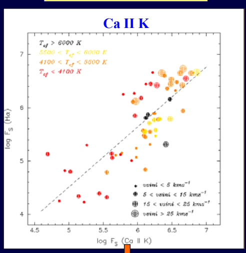


Fig. 6a: log F_s(Hα) vs. log F_s(Hβ) for the stars of the sample.

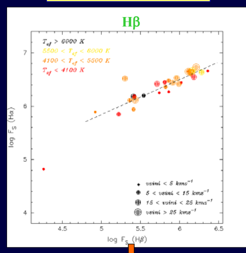
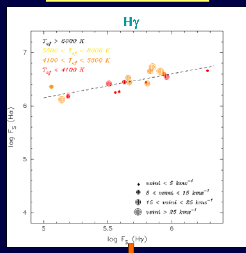


Fig. 7a: log F_s(Hα) vs. log F_s(Hγ) for the stars of the sample.



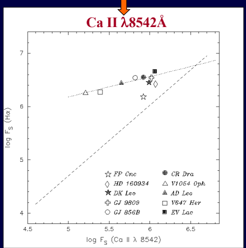


Fig. 4b: log F_s(Hα) vs. log F_s(Ca II λ8542Å) for the flare K7- and M-dwarfs of the sample.

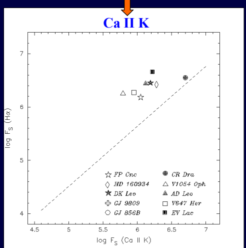


Fig. 5b: log F_s(Hα) vs. log F_s(Ca II K) for the flare K7- and M-dwarfs of the sample.

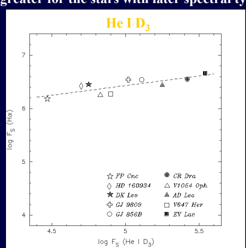


Fig. 8: log F_s(Hα) vs. log F_s(He I D_3) for the flare K7- and M-dwarfs of the sample.

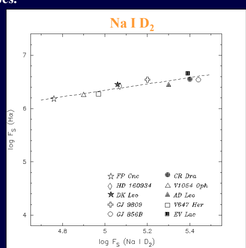


Fig. 9: log F_s(Hα) vs. log F_s(Na I D_2) for the flare K7- and M-dwarfs of the sample.

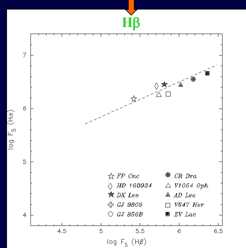


Fig. 6b: log F_s(Hα) vs. log F_s(Hβ) for the flare K7- and M-dwarfs of the sample.

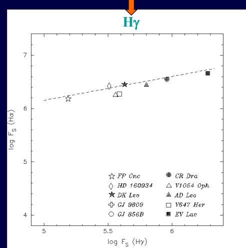


Fig. 7b: log F_s(Hα) vs. log F_s(Hγ) for the flare K7- and M-dwarfs of the sample.

Line Profiles

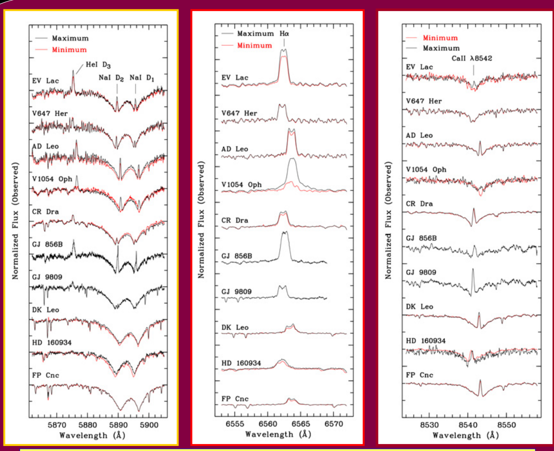


Fig. 10, 11 and 12: Line profiles of the He I D_3 (left), Na I doublet (left), Hα (centre) and Ca II λ8542Å (right) lines for the UV Cet type flare stars of the sample.

For the UV Cet type flare stars of the sample we have plot in Fig. 10, 11 and 12 the observed profile of different chromospheric lines (He I D_3, Na I D_2, Na I D_1, Hα and Ca II λ8542Å). The spectra are ordered by spectral type (the star with the latest spectral type is in the top). The maximum (black) and minimum (red) emission that have been detected in the spectra of each star is shown. Very small variations are detected in almost all the stars, except in the case of EV Lac and V1054 Oph, where a strong flare is present (see the enhancement in the He I D_3 line in both cases and the big enhancement and broadening of the Hα line of V1054 Oph). The minimum spectra show that the Balmer series, He I and Na I lines have a stronger emission when the flare star is cooler, except in the cases of GJ 856B (in which the emission is stronger than normal) and V647 Her (in which the emission is weaker), while the Ca II lines do not show a clear relation with the spectral type. Finally it can be seen that a clear self-reversal is also present in the Hα line.

Conclusions

High resolution spectra of 10 UV Cet type flare stars have been analysed in this work. Age, line profiles, rotation and flux-flux relationships have been studied and the results have been compared with the ones obtained by López-Santiago et al (2004a, b) for a sample of 144 stars, with spectral types from F to M, that are possible members of young stellar moving groups. The excess emission in the Hα line seems to be independent of the rotational velocity in the case of our flare stars. These flare stars are also out of the tendency that the other stars of the sample follow in the flux-flux relationships of Hα vs. the Ca II lines. This can be due to the fact that during the exposure time given to the observations several flares could have taken place, and the enhancement of the Balmer lines is larger than the one of the Ca II lines during this kind of events. However, all the flux-flux relationships seem to be linear, even for our flare stars. Finally, the Balmer series, He I and Na I lines have a stronger emission when the flare star is cooler while the Ca II lines do not show a clear relation with the spectral type.

References

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