Circumstellar Activity and Flares in FK Comae: New Results from the ESA-MUSICOS Spectrograph on the INT

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Abstract.

We present results on the variability and phase behaviour of the Balmer lines in FK Comae. We confirm that these lines are highly variable, with excess emission that originates from extended structures and exhibit clear signs of rotational modulation. We have described the profiles of these lines with a multi-component analysis.

A large flare event lasting several days was detected in both Balmer lines and in the HeI D3 line. The energy released during this flare in Hα was $\sim 10^{37}$ erg, while the total energy in the optical region was estimated to be $10^{39}$ erg, the second largest flare energy ever observed on a cool star.

1. Introduction

FK Comae (HD 117555) is a rapidly rotating and apparently single G5 II giant. This star has an extreme rotational velocity of $v \sin i = 162.5 \pm 3.5$ km s$^{-1}$ (Huenemoerder et al. 1993). The photometric and rotational period are 2.400 day (Jetsu et al. 1993). The Hα emission line in FK Comae is extremely broad and asymmetric and has variations on different time scales. The same characteristics are present in higher Balmer lines (like Hβ). The phase modulation in these lines indicates that the emitting material is co-rotating with the star.

2. Multi-component Analysis

In May 1997, 16 FK Comae spectra of Hα, Hβ and HeI D3 were obtained at the INT, with the ESA-MUSICOS echelle spectrograph. Part of this data set is shown in Figure 1. Additional spectra were obtained in June 1997 on the OHP.

We used a multi-component approach to model this dataset. It consists of fitting a variable number of discrete Gaussian components to each of the spectral lines, representing the emitting structures (Oliveira & Foing 1998). Figure 2

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Figure 1. The Hα, Hβ and HeI D3 average spectra from May 97 (from top to bottom in each graph), after removing the rotationally broadened template. The spectra were displaced vertically for clarity. In each graph, the phase and UT date are also indicated. The ephemeris used is from Chugainov (1976): 2442192.345 + 2.400E. The integer rotation number ordinate describes the continuity of the data set, with the first spectrum of 14 May as reference. Velocity components are noticeable in the spectra and their variations in velocity and intensity were followed (Oliveira & Foing 1998).

shows an example of this multi-component fit, emphasizing the same components in both Balmer lines.

We also analysed the phase behaviour of these structures. The velocity curves that describe the phase behaviour of the emitting structures, as they co-rotate with the star, have equations of the type:

\[
\frac{R}{R_*} \times \frac{v_{eq}}{v} \sin i \cos \theta \sin(\phi + \phi_0) = v_c \times \sin(\phi + \phi_0)
\]

where \(v_{eq}\) is the equatorial rotational velocity, \(\theta\) is the stellar latitude, \(\phi_0\) the stellar longitude and \(v_c\) is the velocity excursion in km s\(^{-1}\).

In Figure 3, we show several plots that characterize the Gaussian components fitted to Hα and Hβ: from bottom to top, the peak intensity vs velocity,
Figure 2. An example of the multi-component fit to the Balmer lines (from top to bottom $H\beta$ and $H\alpha$). It is clear that the same components are present in both spectral lines, except for the higher velocity ones, that are masked in the noise in $H\beta$ (Oliveira & Foing 1998).

and velocity vs phase for both lines. As can be seen in this figure, three structures could be followed in phase, corresponding to $v = 245 \times \sin(\phi + 0.62)$, $v = 285 \times \sin(\phi)$ and $v = 487 \times \sin(\phi)$, both in $H\alpha$ and $H\beta$. The same components and phase behaviour are observed for these two spectral lines.

3. Large Long Duration Flare detected on 16 May 97

A large flare event was detected in the $H\alpha$ and $H\beta$ lines and also in $He \ I\ D3$ (Oliveira & Foing 1998). The velocity curve that describes the phase evolution of the flaring structure in $H\alpha$ and $H\beta$ (Figure 3), corresponds to $v_c \sim 245 \ km/s$ ($R \cos \theta = 1.50 \ R_\odot$) and $\phi_0 = 0.62$. At five other phase positions the same structure is identified. This structure was first detected on May 15 and it was still present on May 21.

This flare event caused an increase in the equivalent width of $7 \pm 1 \ \AA$ in $H\alpha$ and $1.2 \pm 0.2 \ \AA$ in $H\beta$. Assuming a distance of 215 pc (Huenemoerder et al. 1993), the energy released at flare maximum is $8 \pm 1 \ 10^{31} \ erg \ s^{-1}$ for $H\alpha$ and $1.1 \pm 0.1 \ 10^{31} \ erg \ s^{-1}$ for $H\beta$. The total energy released in $H\alpha$ during the flare is $11 \pm 3 \ 10^{36} \ erg$. Assuming a flare ratio UBVRI/He of 120 (e.g. Avrett et al. 1986), the continuum UBVRI counterpart of the FK Comae flare would amount to losses of $1.3 \ 10^{39} \ erg$. In comparison with the observed giant flares
Figure 3. Phase behaviour of Balmer line components (Oliveira & Foing 1998). From top to bottom: peak intensity plotted against phase with the size of the symbols representing the corresponding intensity, • represents Hα and ○ Hβ from INT May 97 and ◆ Hα from the OHP June 97; velocity evolution of the Hα components with phase; velocity evolution of the Hβ components with phase. The estimated maximum error in the velocity determinations is about 50 km s⁻¹. In the bottom two graphs, three velocity curves are over-plotted, corresponding to different distances from the rotational axis and longitudes. The dotted part of these curves represents the occultation of the structures by the star. The points indicated with F are flare spectra. The dashed lines represent ± v sin i from the rotational axis.

UBVRI radiative losses of 1.8 \times 10^{39} erg and 1.2 \times 10^{38} erg found respectively for YY Men (Cutispoto et al. 1992) and HR 1099 (Foing et al. 1994), this would make this flare the second largest flare energy observed.
4. Conclusions

We have applied a multi-component analysis to identify and describe the phase behaviour of emission components in Hα and Hβ. A strong flare event was detected in these two Balmer lines and in HeI D3. The total energy released during the flare in Hα is $\sim 10^{37}$ erg, one of the largest flare energy observed on a cool star.

The need is clear for a multi-site continuous data set to disentangle the intrinsic variations from rotational modulation. We have organized a multi-site campaign in February/March 1998, involving the following telescopes and observatories: INT (with the ESA-MUSICOS spectrograph), Telescope Bernard Lyot, France (with the MUSICOS spectropolarimeter), David Dunlop Observatory (Canada), Russian Special Astrophysical Observatory (SAO) and McDonald Observatory. The phase coverage thus obtained represents a major improvement in the analysis of the circumstellar emission on FK Comae.

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