FR Cnc Nature Revisited

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Abstract

The results of photometric and spectroscopic monitoring of FR Cnc reported a tricky nature. We carried out several observations at different observatories in India, Russia, Ukraine and Spain during several years to characterize and discover the source of its radial velocity variations. After discard a binary nature in first instance due to its high level of activity, further detailed and complete study lead as to still take into account the presence of a stellar companion possibility. We present here the study of this star and preliminary conclusions about its real nature.

Chromospheric activity indicators

We determined the chromospheric contribution in different chromospheric activity indicators by using the spectral subtraction technique, Montes et al. (1995; 1997; 1998). We measured the excess emission equivalent width, (EW), in the subtracted spectra for the main optical and near infrared indicators for the echelle spectra and transform into absolute superficial flux ($logF_s$) (Table 1). Also we folded radial velocities with the rotational period (0.8267d) – see figure 1. Examples of the profiles of the *Hα* and *Ca II IRT* (8498, 8542) lines are plotted in Figure 2 left side for echelle data and in Figure 2 right side for long-slit data. *Hα* line is observed always in emission above the continuum in the observed spectra. This emission is persistent during all observation indicating that it is a very active binary system similar to some RS CVn and BY Dra systems. Absorption of the three, *Hβ*, *Hγ* and *Hδ* lines filled in with emission is seen too, sometimes with emission above the continuum. Also, a clear emission filling the absorption line is observed in the core of the Ca *II IRT* absorption lines. To study the origin of the emission lines, we have studied two known relations between Balmer lines and between Ca II IRT lines. We measured the ratio of excess emission in the *Hα* and *Hβ* lines, EW(H*α*)/EW(H*β*), and the ratio of excess emission E(H*α*)/E(H*β*), with the correction given by Hall & Ramsey (1992). This takes into account the absolute flux density in these lines and the colour difference in the components. We obtained mean values of 3.65 and 5.64 respectively, that indicate Balmer lines comes from prominences-like structures above the stellar surface. The ratio between Ca II IRT (E(8542Å)/E(8498Å)) has a 1.26 average, that indicate this emission arises from plage-like regions at the stellar surface (Chester 1991).

Observations

We obtained *spectroscopic* observations of this star in three observing runs dedicated to high and low resolution respectively:

1) March-April 2004. Using the Fibre Optics Cassegrain Echelle Spectrograph (FOCES) (Pfeiffer et al. 1998) in the 2.2 m. telescope at the German Spanish Astronomical Observatory (CAHA) (Almería, Spain).

2) April 2004. Using the low resolution Himalaya Faint Object Spectrograph And Camera (HFOSC) in the 2.2 m. telescope of The Indian Astronomical Observatory (Mt. Saraswati, Hanle, India).

3) March 2008. Using The high-resolution Fibre-fed Echelle Spectrograph the 2.56 m. Nordic Optical telescope (NOT) at the Roque de los Muchachos Observatory (La Palma, Spain).

We obtained the *photometric* observations at CrAO (Crimean Astrophysical Observatory, UKRAINE) during 4 nights on November, 2006 with the help of 38-cm Cassegrain telescope and SBIG ST-9 CCD camera, as well as in Terskol Observatory (Terskol, RUSSIA) during 7 nights in March, 2007 using 0.29-m telescope and Apogee-47 Alta CCD camera. Additional photometric monitoring was carried out in Terskol during 7 nights in February, 2008 with the same equipment as in 2007.

Table 1

Night (FOCES04)	CaII K	CaII H	Hε	Hδ	Hγ	Hβ	Hα	CaII IRT λ8498	CaII IRT λ8542	CaII IRT λ8662
n5	?	?	?	?	5.88	6.35	6.91	6.24	6.38	6.28
n6a	6.02	?	?	6.03	6.30	6.42	7.00	6.26	6.36	6.25
n6b	?	?	?	?	5.86	6.46	7.04	6.28	6.37	6.31
n6c	?	?	?	?	5.92	6.34	6.95	6.36	6.38	6.27
n7a	6.41	6.66	6.46	5.56	6.08	6.41	6.95	6.26	6.39	6.74
n7b	6.42[1]	6.39	6.09	5.63	5.73	6.31	6.91	6.25	6.37	6.25
n8a	?	?	?	5.84	6.14	6.33	6.91	6.22	6.36	6.26
n8b	?	?	?	?	5.69	6.39	6.95	6.25	6.33	6.24
n9a	6.55	6.47	6.23	?	6.14	6.38	7.03	6.22	6.36	6.26
n9b	?	?	?	?	?	6.45	6.98	6.28	6.35	6.27

Notes:
1. values measured with very low s/n
2. values not measured due to very low s/n

Photometry

First photometry allow us to detect a flare in FR Cnc on 23 November, 2006 with the maximum at 00:19 (UT) (Figure 3). After the initial rapid flaring, the brightness of FR Cnc decreased slowly. The time between the flare began and reached its maximum was about 4 minutes, while the total duration of the flare was about 41 minutes. The flare had a maximum amplitude (1.^{m}02) in the B band. In other bands the amplitudes were 0.^{m}49, 0.^{m}21 and 0.^{m}14 for V, Rj and Ij bands respectively. Noteworthy, in 8 minutes after the flare's maximum a notable ``spike'' was observed in B and V bands (in other bands the amplitude was probably too low) during the brightness decline. It is remarkable that FR Cnc remained to be about 0.m05 brighter for at least an hour after the flare began comparing with brightness before flare. Following the idea, described at Kozhevnikova et al. (2006), we calculated the intensity of the flare and the absolute energy output. More details could be found in Golovin et al. (2007).
Further photometry follow up allow us to obtain a light curve. We plot the light curve folded with FR Cnc rotational period of 0.8267 days in Figure 4 for 2007 season and in Figure 5 for 2008. As could be clearly seen, one-humped 0.^{m}17 variations with the rotational period are clearly distinguishable, while no flares were detected that could imply that flares is a rare event for FR Cnc.

Fig. 4

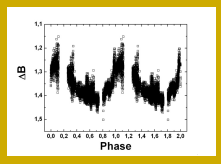
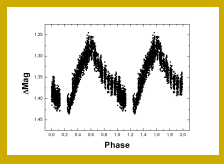


Fig. 5



Bisector study

FR Cnc is a K7V star with a rotational velocity of aprox. 35 km/s, so it is expected to show large dark photospheric spots that produce rotational modulation of light from its surface. To study spectroscopic variations produced by spots, we have chosen bisector techniques.
First results showed that the radial velocity (RV) variations found in this star were induced by stellar activity due to changes in the profile of spectral lines caused by the presence of spots (Saar et al. 2007). But, follow up studies suggest another additional source, a possible companion. The relationship of bisectors of the cross-correlation function and RV is a powerful method to discriminate if the RV variation is due to stellar activity or light contamination from an unseen stellar companion or mechanical motion around the barycentre of a star-planet system (Queloz et al. 2001; Martinez-Fiorenzano et al. 2005). The cross-correlation function (CCF) determined for FR Cnc was limited to regions ranging from 6300 to 6465 A and 6670 to 6760 A, which includes lines commonly used in Doppler imaging. We calculate the bisector, and to quantify the changes in the CCF bisector, the difference of the average values of the top and the bottom zones of bisector is determined ($\Delta\lambda_{bis}$), (Dempsey et al. 1992, López-Santiago et al. 2003). We found a clear correlation between RV and the $\Delta\lambda_{bis}$, with a positive slope, (see Fig. 6).

Fig. 3

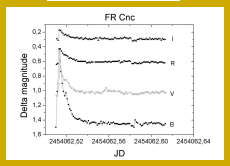


Fig. 1

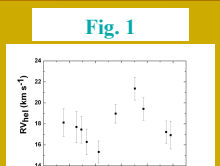
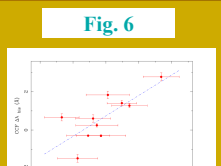


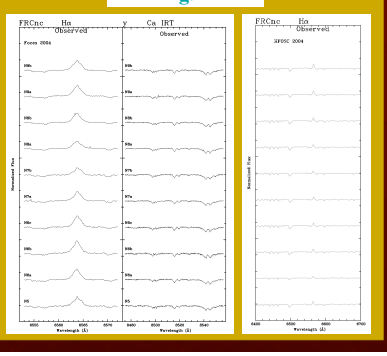
Fig. 6



Spectral Clasiffication

Classified as a K8V in Simbad, a detailed photometric study allowed to classified FR Cnc as a K5V by Pandey 2005. He also obtained the Spectral Energy Distribution (SED) of the star matching a T_{eff} of 4250±250 and a log g of 4.50±0.5, that agrees with a K5V classification.
We compared our high resolution echelle spectra, in several spectral orders free of lines sensitive to chromospheric activity, with spectra of inactive reference stars of different spectral types and luminosity classes observed during the same observing run. This analysis makes use of the program *starmod* developed at Penn State University (Barden 1985) which we modified later. This program constructs a synthesized stellar spectrum from artificially rotationally broadened, radial-velocity shifted, and weighted spectra of appropriate reference stars. For FR Cnc, we have obtained the best fit with a K7V reference star, in agreement closer to the K8V classification from the literature than Pandey 2005. See references for further information.

Fig. 2



Conclusions

- FR Cnc is a K5-7V, chromospherically active star. Here we found spectroscopic and photometric evidences of photosphric spots. In addition, prominence-like structures are inferred from the chromospheric activity indicators.
- On 23 November, 2006 the large optical flare was detected in BVRI bands. Further optical photometry did not revealed any other flares in FR Cnc. On the other hand, 0.m17 brightness modulations with rotational period were detected in B-band during quiescence state of FR Cnc in 2007 and 2008.
- Kinematic studies suggest that FR Cnc is a very young (35-55 Myr) main sequence star and that is a possible member of IC 2391 supercluster (Pandey et al. 2005).
- Rotational velocity (*vsini*) is equal to 35.58 km/s. Radial velocities were determined in all our spectroscopic observations. We have found a radial velocity variations correlated with the rotational period and with line asyemmetries quantified with the line bisectors.
- Further bisector and photometry studies are actually on going to help us to finally discriminate the source of the radial velocity variation and clarify the real nature of FR Cnc.

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