SPECTROSCOPY OF THE MYSTERIOUS BE SYSTEM FF CAM

T. GARREL¹, A. S. MIROSHNICHENKO², S. DANFORD², S. CHARBONNEL³, F. HOUPERT¹, K. N. GRANKIN⁵, and A. V. KUSAKIN⁶

¹ Observatoire de Foncaude, Montpellier, France
² University of North Carolina at Greensboro, Department of Physics and Astronomy, Greensboro, NC, USA
³ Durtal Observatory, Durtal, France
⁴ Verny Observatory, Verny, France
⁵ Crimean Astrophysical Observatory, Nauchny, Ukraine
⁶ Fessenkov Astrophysical Institute, Almaty, Kazakhstan

Abstract. FF Cam is a variable star near the North celestial pole with hydrogen lines in emission. Its optical variability of \(\sim 0.3\) mag was discovered by HIPPARCOS. The spectral type assigned to the star in SIMBAD is B9, but its position coincides with a ROSAT X-ray source. This suggests the presence of a high-temperature region in the system that could originate at or near a companion object. We undertook a spectroscopic monitoring of FF Cam since the beginning of 2012 and found an extremely variable H\(\alpha\) line profile as well as periodically variable radial velocities of numerous absorption lines. The main conclusion from our study is that FF Cam is a binary system with an orbital period of 7.785 days, a B-type primary and a K-type secondary component. We discuss the spectral features, their variations, and the nature of FF Cam.

Key words: Emission-line stars - circumstellar matter - binary systems

1. Introduction

FF Cam = HD 60062 is a fairly bright (\(V \sim 7.5–8.0\) mag) star not far from the North Celestial Pole (R.A. 7h 47m, Dec. +81°40′, 2000). It was discovered as a variable star by the HIPPARCOS mission (ESA 1997) that obtained 146 measurements of its visual magnitude on 38 different days in 1989–1993 (see Fig. 1b). These data were first analyzed by Woitas (1997), who found no periodic variations. The object was included in the General Catalog of Variable Stars as FF Cam (Kazarovets et al. 1999) and classified as a Be star. We are still searching for the origin of this classification, although it does have an emission-line spectrum. An ROSAT X-ray source
with a flux of 0.15±0.02 counts s⁻¹ was recently found in 0″1 from the visible/IR star position (Haakonsen & Rutledge 2009). FF Cam is located far from the Galactic plane (b = 29°) that implies a low reddening. Its HIPPARCOS parallax leads a distance of 580⁺270⁻150 pc (ESA 1997) which may be wrong, if the object is a binary system (see Sect. 3). Both the distance and apparent brightness suggest that the system is not very luminous. The current presentation is the first study of the spectroscopic behavior and the spectral energy distribution of FF Cam.

![Figure 1](image1.png)

*Figure 1:* The Hα line profile variations in the spectrum of FF Cam in January – February 2012. Intensity is normalized to the underlying continuum, radial velocity is heliocentric.
2. Observations

Photometric \textit{UBVRI} observations were obtained on 2012 April 13 and 15 with the 1.25–m telescope of the Crimean Observatory in Ukraine. \textit{BVR} observations were obtained on 2012 April 11, 12 and May 24 with a 0.2–m Newtonian reflector at the Tien-Shan Observatory near Almaty, Kazakhstan. Medium-resolution spectra were obtained at three amateur sites in France (Montpellier, Durtal, and Verny) and in the USA at the Three College Observatory (TCO, near Greensboro, North Carolina). Two types of spectrographs were used: long-slit LHires III in the H\(\alpha\) region with a spectral resolving power \(R \sim 17,000\) and échelle (\(\lambda\lambda\) 4300–7200 \(\text{Å}\), \(R \sim 10,000\)). All the spectrographs were manufactured by the Shelyak company (www.shelyak.com). In total we obtained over 100 spectra in 2010–2012, mostly in January–April 2012. IRAF was used to reduce the TCO data, the amateurs data were reduced with software packages developed for amateur spectrographs (Audela\(^1\) and ISIS\(^2\)).

3. Results

The main features of the FF Cam optical spectrum are the following. The Balmer H\(\alpha\) and H\(\beta\) lines are seen in variable emission with mostly single– or double–peaked profiles (see Fig. 1), while almost no emission is observed in H\(\gamma\). Fe II lines show weak double-peaked emission profiles. He I lines are in absorption. Numerous absorption lines of neutral metals are weak (\(\leq 10\%\) of the continuum, see Fig. 2a).

Strong absorption components of the H\(\beta\) and H\(\gamma\) lines and strong pure absorption He I lines along with weak absorption lines of neutral metals imply that FF Cam has a composite spectrum. It is a binary system with a brighter B–type component (later than B2) and a cooler, fainter component probably of an early K–type. The temporal behaviour of the emission-line spectrum (Fig. 2b) implies that the amount of circumstellar gas in the system varies with time.

Analyzing radial velocity variations, we found them strictly periodic and sinusoidal (Fig. 3a). Therefore, the binary orbit is circular. The following orbital elements were determined. Radial Velocity Maxima = JD 2455941.594

\footnote{1http://www.audela.org/dokuwiki/doku.php/en/start}
\footnote{2http://www.astrosurf.com/buil/isis/isis_en.htm}
Figure 2: \textbf{Panel a.} Absorption lines in the spectrum of FF Cam at different phases of the orbital cycle. Intensity is normalized to the underlying continuum. Radial velocity is measured by fitting the line profiles to a Gaussian. \textbf{Panel b.} Variations of the H$\alpha$ line equivalent width measured by intensity integration with the line profile in the continuum normalized spectra. Only the emission component of the line profile was used for the measurements.

+ 7.785$^\pm$E (days). The radial velocity semi-amplitude for the cool component $K_2 = 85.0$ km s$^{-1}$. These elements lead to a mass function of $f(M) = 0.5 M_\odot$.

The emission line intensity variations do not correlate with the orbital period. Since the stars are very close to each other, the cool component most likely fills its Roche lobe. This can cause mass transfer into the Roche lobe of the hot component and formation of an accretion disk around it.

Absorption lines of the hot component move roughly in anti-phase with those of the cool component, but they seem to be contaminated by the accretion disk. Small variations of the cool component line intensities and chaotic brightness variations (Fig. 3b) suggest no eclipses in the system.

The low value of the mass function and the presence of a B–type star in the system imply that the system is viewed nearly pole-on. For a lower limit of 5 $M_\odot$ for the system mass, the orbital inclination angle is $27^\circ$. Assuming the HIPPARCOS distance, no interstellar reddening, and a components brightness ratio of $\Delta V = 1$ mag (Fig. 4), the cool component’s radius is 10 $R_\odot$. The X–ray flux is $\sim 10^{-5}$ of the hot star optical flux. This is over
Figure 3: Panel a. Absorption-line radial velocity curve of FF Cam. Panel b. Visual brightness variations of FF Cam plotted against the spectroscopic orbital phase. Filled circles are HIPPARCOS data, open circles are V-band magnitudes from Crimea.

an order of magnitude larger than the expected photospheric flux from the B–type component. Our current data offer no explanation to this fact.

4. Conclusions

We have found that FF Cam is not a Be star, but rather a short-period (7.785 days) semi-detached binary system with mass transfer from the cool component to the hot component. The mass transfer is variable and results in fast variations of the emission-line profiles as well as in the observed photometric variations. High-resolution spectroscopy with a good phase coverage and high signal-to-noise spectra are needed to constrain the component spectral types and orbital parameters.

Acknowledgements

A.M. acknowledges support from the American Astronomical Society International Travel Grant program and from the Department of Physics and Astronomy of the University of North Carolina at Greensboro. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France, data products from the Two Micron All Sky Survey (2MASS) and the Wide-Field Infrared Survey Explorer (WISE), and the BeSS database,
Figure 4: Spectral energy distribution of FF Cam. Symbols: filled upward triangles – TD1 UV satellite, filled circles – Crimean $UBVRI$, filled squares – 2MASS $JHK$, filled downward triangles – WISE, open circle – AKARI, open square – IRAS. The thick line is a Kurucz (1993) model atmosphere for a B7–star (70% contribution to the observed flux), the thin line is a model atmosphere for a K0–star (30% contribution). No interstellar extinction is taken into account.

operated at LESIA, Observatoire de Meudon, France (accessible at [http://basebe.obspm.fr](http://basebe.obspm.fr)).

References

ESA 1997, European Space Agency SP–1200. The Hipparcos and Tycho Catalogues.

Haakonsen, C. B., and Rutledge, R. E.: 2009, Astrophys. J., Suppl. Ser. 184, 138.

Kazarovets, E. V., Samus, N. N., Durlevich, O. V., et al.: 1999, IBVS, 4659.

Kurucz, R.L.: 1993, CD-ROM No. 13, Smithsonian Astrophysical Observatory.

Woitas, J.: 1997, Inform. Bull. Var. Stars, No 4444.