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Research Note

A potential ϕ Per-type (Be+sdO) binary: FY CMa*

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Abstract. The spectrum of the Be star FY CMa is shown to vary periodically with $P = 37.26 \pm 0.03$ d. The types of variation, exhibiting transient strong shell phases and a radial-velocity variable He I emission component, suggest the star to be of the same type as ϕ Per, i.e. having an evolved hot companion ionizing the outer parts of the primary's circumstellar disc where it faces the hot companion. After ϕ Per and the candidates 59 Cyg and HR 2142, this is only the fourth promising candidate, although such systems should be relatively abundant. The similarities found between ϕ Per, 59 Cyg, and FY CMa include a radial velocity-variable He I emission feature and a phase-locked V/R cycle. An ephemeris is given that allows a test of the proposed recurrent nature of a strong shell feature observed only in a single spectrum at present.

Key words. stars: emission-line, Be – stars: binaries: spectroscopic – stars: individual: FY CMa

1. Introduction

The Be star ϕ Persei is accompanied by an evolved, but non-degenerate, companion, namely an sdO star. The primary is supposed to be almost critically rotating due to spin up by the mass transfer from the evolving companion, i.e. before the system reached the current state. The current circumstellar disc is not a remnant of this mass-transfer, but has been ejected from ϕ Per itself, presumably by the same mechanism acting in other Be stars. Although spun-up systems of this type should exist in abundance, they are hard to detect (see review by Gies 2000, and references therein). The companion of ϕ Per was confirmed only by ultraviolet IUE and HST spectra (Gies et al. 1998).

Poeckert (1981) described the orbital cycle of ϕ Per and showed numerous example profiles. Štefl et al. (2000) and Hummel & Štefl (2001) investigated ϕ Per and could model most of the observed phase-locked variations of the He I-lines as due to the outer edge of the circumstellar disc being excited by the radiation of the sdO companion. Both emission and absorption variations originating in the circumstellar environment were modelled. Because the primary is seen through the edge-on disc, phase-locked narrow absorptions occur during superior conjunction, when the ionized edge of the disc is in the line of sight. Due to the increased rate of recombination in this region, a higher number of absorbers will be found in the lower states of various transitions. As these are not the respective ground-states of the ions, they are less populated in the non-ionized region. Only two other objects proposed to be of an Be+sdO nature can be regarded as promising candidates. For one of them, 59 Cyg, Maintz (2003) could isolate the secondary's photospheric spectrum of He II 4686. For HR 2142, proposed as such a binary by e.g. Waters et al. (1991), a scenario of an interacting binary has been proposed by Peters (1983), but its nature is not yet known with certainty.

The Be star FY CMa (HR 2855, HD 58 978, B0.5IVe) has been known to exhibit emission since the report of Pickering & Fleming (1905). Later, Burbidge & Burbidge (1954) observed shell-type absorption, i.e. narrow absorption superimposed on the rotationally broadened lines. This absorption is present in those lines of He I that arise from metastable levels, like He I 3889, and they explicitly stated such narrow absorption to be absent in He I lines arising from other levels. This general description of the shell-type spectrum was confirmed by all observers who took spectra of the blue region in the following decades (Slettebak 1982, and references therein).

Despite this continuous presence of what was called a helium shell, the emission profile appearance varies on relatively short timescales, both in shape and intensity, with respect to other Be stars (see e.g. Peters 1988; Hanuschik et al. 1996). Peters (1988) and later Cao (2001) also noticed variable features in He I 6678 and He I 5876, respectively, which Peters describes as alternating between a P Cygni and inverse P Cygni

* Based on observations collected at the South African Astronomical Observatory.

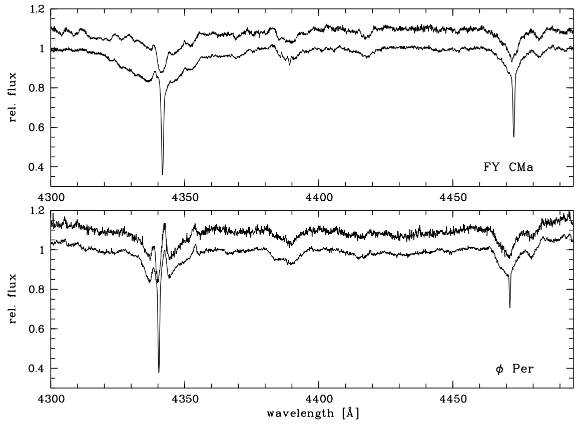

Fig. 1. Comparison of the two spectra of FY CMa by Chauville et al. (2001) with those of ϕ Per by Štefl et al. (2000), both in- and outside a shell-phase.

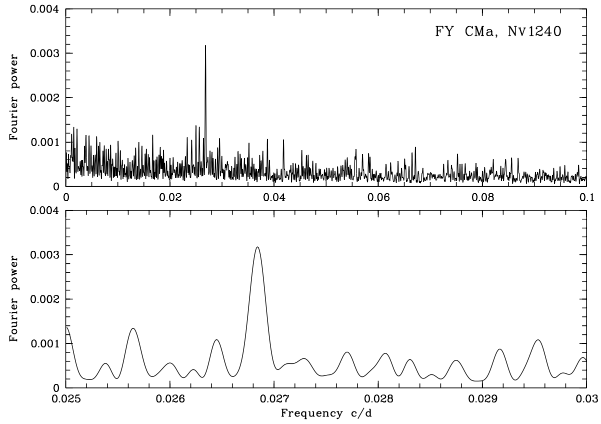

Fig. 2. Fourier signal of the local intensity variations in the N V 1239/43 doublet, summed across the line profile. The lower panel is a close-up of the upper one.

profile, while Cao observed only the inverse P Cygni state. Based on these observations, Peters (1988) proposed the star to be a binary with a cool, undetected companion. The variability would then be caused by line-of-sight effects of ongoing mass-transfer. Cao (2001) favours an alternative explanation, including closed magnetic loops channeling polar outflow to the equator, reaccreting onto the star.

While such scenarios cannot be excluded on the basis of the current data, we show that all observations are also consistent with a classical Be star, i.e. having a disc formed by matter ejected from the primary Be star (Porter & Rivinius 2003), orbited by an evolved hot subdwarf like ϕ Per. In such a scenario all variability is due to radiative effects of the UV-rich hard radiation of the companion as it orbits the primary.

This idea was sparked by a spectrum taken on JD = 2 447 928.67 (Ballereau et al. 1995) and made available online by Chauville et al. (2001). This spectrum shows a strong shell-type absorption in Hδ, He I 4471, and faintly in He I 4388. No other investigator has mentioned such a spectral appearance, and in another spectrum published by Chauville et al. (2001), taken on JD = 2 448 638.70, these shell absorptions are absent (see Fig. 1). This made FY CMa a promising target for a comparison with ϕ Per, which shows a transient shell-type spectrum at superior conjunction, i.e. when the primary is behind the secondary. The similarity even goes further, since in ϕ Per narrow absorption of transitions originating from meta-stable He I levels, like He I 3889, is also always present. This absorption is stronger at times of superior conjunction in ϕ Per.

Periodic variations were indeed detected in photometry by Sterken et al. (1996), but the period of 92.7 days could not be confirmed with spectroscopic data. The available radial velocities are single measurements only, given in radial velocity catalogues, and are of the order of 25 to 48 km s^{-1} (Duflot et al. 1995; Reed & Kuhna 1997).

2. New observations

Eleven spectra have have been obtained with the fiber-fed echelle spectrograph Giraffe attached at the Cassegrain focus of the 1.9-m Radcliffe telescope of the SAAO, Sutherland, between December 5 and 16, 2003. The sampling was one spectrum per night with a typical S/N of 80–100. The resolving power of the spectrograph is 39 000. The instrumental setup was fixed to the red prism position for the whole observing run. By increasing the prism angle we accessed the intermediate wavelength range of 4250–6800 Å, covered by 49 echelle orders. The SAAO TEK6 CCD camera contains a Tektronix 1024 × 1024 chip with pixels of 24 μ. As is it customarily done at the Giraffe spectrograph, flat fields were taken both through the fiber and by illuminating a sheet of paper directly in front of the camera, bypassing all dispersive optics. Only the fiber flat fields produced by the tungsten lamp were used both for blaze correction and order definition in the final reduction. The Thorium-Argon calibrations were taken every 30–40 min in order to follow drifts of about 0.2–0.5 pixels during the night. The data were reduced using the MIDAS context "feros" (Kaufer et al. 1999), which was adapted to the Giraffe spectra.

3. Time series analysis of archival and newly observed data

3.1. IUE data

In the data archive of the International Ultraviolet Explorer satellite (IUE), 96 spectra taken with large aperture and at high resolution in the short wavelength range were found for FY CMa. The resonance wind lines in these data of Si IV, C IV, and N V were analyzed with a 2-D time series analysis technique described by Kaufer et al. (1996). A significant period well above the noise level and not showing ambiguous aliases was found at P = 37.26 ± 0.03 d (Figs. 2 and 3) in all three doublets. As a test, several subsets of the IUE spectra were analyzed separately, giving the same period.

The IUE spectra were sorted by phase into 16 bins. These phased spectra were searched for a contribution of a hot companion, in particular at He II 1640, but nothing could be found. The UV spectral energy distribution is not obviously different from what one would expect for a B0.5 star, but this does not exclude an sdO companion, which would contribute only a few percent to the flux in the IUE spectral range.

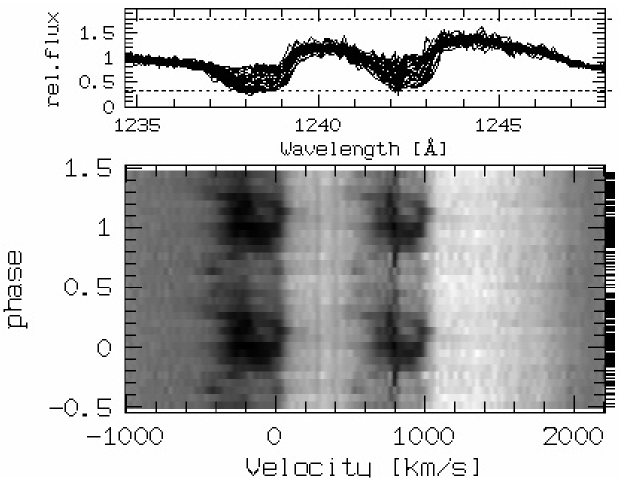

Fig. 3. IUE-profiles of the N V 1239/43 doublet phased with P = 37.26 d and epoch JD 2 447 928.6. The intensities were translated to grey scale. Two cycles are shown for clarity.

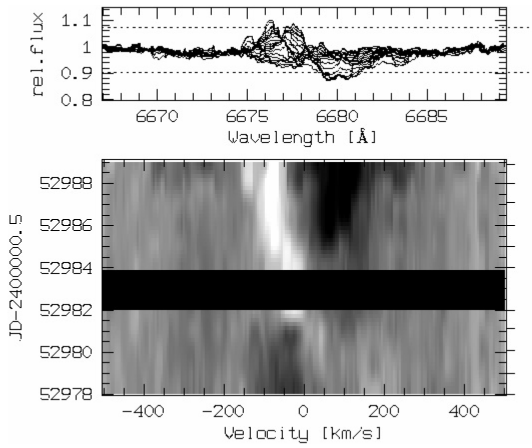

Fig. 4. He I 6678 profiles observed by us sorted by date and with intensity translated to grey scale. In the 11 nights of observation, an emission feature can be seen moving from red to blue, while the absorption moves in the other direction.

3.2. Visual data

In order to test this period, previously published line profiles of FY CMa were inspected, in particular the series by Peters (1988) and Hanuschik et al. (1996). For this purpose, we adopt the period derived from IUE data and the date when Ballereau et al. (1995) observed strong shell absorption as epoch for phase zero, i.e.:

$T_{\rm shell}$ = JD 2 447 928.67 + $E \times 37.26 \pm 0.03$.

Peters (1988) observed Hα and He I 6678 on Feb. 2, on April 16−20, and on May 2−6, 1987. Hanuschik et al. (1996) observed Hα on Feb. 8, 1987, Jan. 12 and Mar. 24, 1992, and Apr. 18, 1993. For the profiles taken before the above given epoch, we give both the E and the phase ϕ, for profiles taken after the epoch, ϕ can be read directly from E.

Peters noted her 1987 profiles of February ($E = -29.52, \phi = 0.48$) and April ($E = -27.56 \ldots -27.45, \phi = 0.44 \ldots 0.55$) to be only slightly different from each other; they all show a somewhat higher violet peak of the double-peaked profile. The apparent absorption in the blue peak observed by Peters is of telluric origin. Hanuschik et al.'s profile of February, 1987, ($E = -29.36, \phi = 0.64$) does clearly differ from this appearance. Since Hanuschik et al. have removed the telluric lines the triple-peaked appearance of the profile at $\phi = 0.65$ is real. This is probably better seen in Fig. 4 of Cao (2001), who uses the same spectrum, but plots it on a more favourable scale to estimate such effects. Thus the profile must have changed between February and April 1987. Hanuschik et al.'s profiles of 1992 (E = 18.92 and 20.85) both look similar to those taken by Peters in May 1987 ($E = -27.13 \ldots -27.02, \phi = 0.87 \ldots 0.98$), namely with a very strong violet peak compared to the red one. Finally Hanuschik et al.'s 1993 profile at E = 31.32 differs from all other ones, as it is the only one where the red peak is stronger, in fact much stronger, than the violet one. Sorting all published profiles with the proposed phases would give a cyclic variation of the violet-to-red peak height ratio, with the $V \gg R$ phase between ϕ = 0.75 and 1.00.

Our own recent spectra, shown in Figs. 4 and 5 and covering $E = 135.52 \ldots 135.81$, match well this general phase appearance estimated from Peters' and Hanuschik et al.'s profiles taken at similar phases, but the Hα variations seem not to be as strong as they were in the early 1990s. One new spectrum obtained at E = 135.79 does show enhanced narrow absorption in the higher Balmer lines and narrow absorption in He I 5016. Also He I 4922 shows such an absorption, but is not plotted here since it is very similar to He I 5016. This absorption is redshifted by about 115 km s^{-1} to the terrestrial frame. Neither the preceding nor the following spectra, taken the day before and after, respectively, show this additional absorption.

Sterken et al. (1996) reported a 92.7 d period in photometric data, also obtained over several years. To test this period, archival data from the Hipparcos mission (Perryman et al. 1997) was analyzed independently. A time-series analysis (TSA) on the unmodified data gave two periods of 110 and 1131 days. The latter is on the time scale of the length of the data string itself, therefore, it was subtracted from the data to pre-whiten for a potential long-term trend. TSA on the resulting residual data suggests a period of about 109.5 days (see Fig. 6), but the data is also sorted quite well with Sterken et al.'s period of 92.7 d. The spectroscopically derived period of 37.2 days is not commensurable with any of those photometric time-scales, and the spectra are not sorted well by the photometric period. This can also be estimated from Fig. 2 (upper panel), showing no peak at all at a frequency of $1/92.7 \approx 0.0108$ c/d.

4. Discussion

The spectroscopic variability of FY CMa is dominated by a period of 37.26 d both in the UV and optical domain. All investigated spectra separated by an integer number of cycles do look very similar, but over several years additional secular changes are present as well.

In the newly obtained data, the He I 6678 and He I 5876 lines are dominated by emission (see Fig. 5 for the example

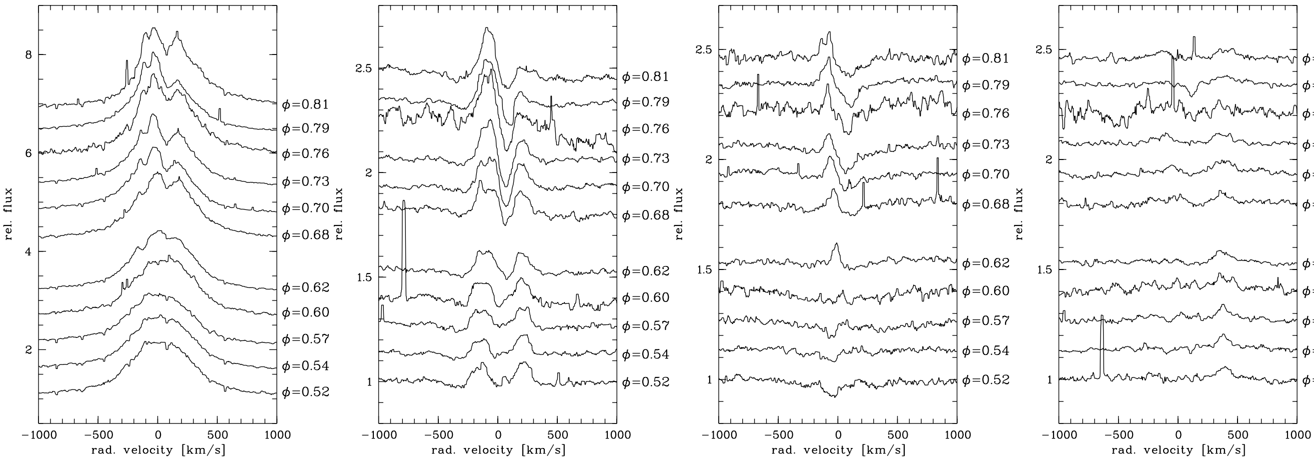

Fig. 5. Variability of Hα, Hβ, He I 6678, and He I 5016 during the SAAO campaign. The phases are given with respect to the ephemeris in Sect. 3. Since the spectra were severely affected by cosmic rays, they have been median filtered for display.

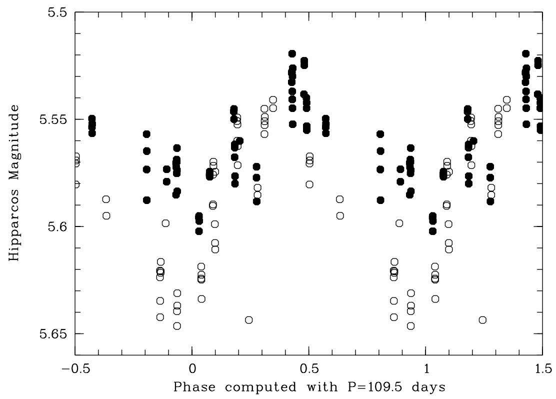

Fig. 6. Hipparcos photometric data sorted with a 109.5 day period. Phase zero was taken as JD = 2 447 928.67. Data obtained before and after JD = 2 448 400, when a slow and steady decrease in brightness started until the end of the observations, are marked by filled and empty symbols, respectively. Note that the original measurements are shown, not the prewhitened data used for the final time series analysis.

of He I 6678; He I 5876 behaves qualitatively the same). The classification of He I 6678 as an inverse P Cygni profile at times is confirmed phenomenologically, but the temporal evolution of the profile suggests a mechanism other than infall. Rather, the line seems to consist of a moving emission component, swaying from the red side of the profile to the blue one during the SAAO observations (Fig. 4), superimposed on a countermoving photospheric absorption profile. All this is strongly reminiscent of the variations of He I 6678 in ϕ Per, as seen in Figs. 5 and 6 of Hummel & Štefl (2001). If all available Hα profiles are sorted with the given ephemeris, the V/R ratio appears cyclically variable, also with a similar phasing as in ϕ Per.

The spectrum published by Chauville et al. (2001) is the only record of a strong shell phase. However, it is also the only known spectrum in the phase interval 0.98 (data from Peters 1988) to 0.32 (data from Hanuschik et al. 1996). The length of the shell phase (i.e., the azimuthal extent of the high-excitation region of the disc) is, therefore, only marginally constrained and could even undergo long-term variations. However, the new SAAO spectrum at $\phi = 0.79$ shows weak shell absorption in He I 4922 and 5016 (see Fig. 5 for He I 5016). This is analogous to ϕ Per, having enhanced shell absorption around the orbital quadrature phases (Poeckert 1981), although a fully consistent explanation of these secondary absorptions in ϕ Per is not yet known. Accordingly, periodic repetition of the strong shell phase also in FY CMa can be expected. The data do not allow us to search for orbital velocity variations in the photospheric absorption lines, but the changes of other emission lines like Hβ Fe II 5317 are analogous to ϕ Per. Hβ, as shown in Fig. 5, for instance, exhibits minor satellite absorptions in the blue emission peak around phase $\phi \approx 0.7$. For further comparison, we refer to Fig. 2 of Poeckert (1981).

The similarities found between ϕ Per and FY CMa are the persistent He I 3889 absorption, an only transiently present strong shell phase, a weaker shell phase close to $\phi = 0.75$, a RV-variable He I emission feature, and a phase-locked V/R cycle. The latter two are also similar to 59 Cyg, another Be+sdO system lacking the shell phases, probably because of unfavourable inclination. The period of 37.26 d is in the same range as the orbital periods of 59 Cyg (28.19 d), HR 2142 (80.86 d) and ϕ Per (127 d). Therefore, a Be+sdO nature for FY CMa should be considered a strong hypothesis.

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