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*Letter to the Editor*

# Is $\beta$ Crateris a Sirius–like system? ⋆

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**Abstract.** New radial velocity (RV) measurements were obtained for the star $\beta$ Crt, which has been suspected to be a Sirius–like binary. Although a preliminary period analysis indicated a period as short as 8 days, no significant change of the RV over 8 nights could be detected. While this result is similar to what Smalley et al. (1997) found, our value of the mean RV is much smaller. We, therefore, conclude that the RV of $\beta$ Crt is indeed variable, maybe but not necessarily due to binarity, but so far no period can be determined.

**Key words:** stars: binaries – stars: binaries, spectroscopic – stars: individual: $\beta$ Crt

## 1. Introduction

Sirius–like systems, i.e. binaries consisting of an early type star and a white dwarf, are quite interesting because of their evolutionary history, probably involving mass exchange. There are not many Sirius–like systems known.

$\beta$ Crt (HD 97277 = HR 4343) is a bright (V = $4\overset{m}{.}5$) star of type A2 III (Levato 1972, Smalley et al. 1997). Its radial velocity (RV) has been measured sporadically during the beginning of this century and the measurements were reported by Campbell & Moore (1928). Although the star was found to have variable RV (between –3 and +16 km s$^{-1}$), and although it is bright with "good lines", surprisingly no one seems to have observed it since then, until recently.

In 1991, a white dwarf was detected at the position of $\beta$ Crt by the ROSAT X–ray and EUV surveys (Fleming et al. 1991). From this and the earlier reported variable RV it was suspected that $\beta$ Crt is a Sirius–like system with an orbital period of $P \lesssim$ 160 days (the estimate by Fleming et al. 1991, as corrected by Smalley et al. 1997). However, Smalley et al. (1997) report on spectra taken for the purpose of elemental abundance analyses, from which they also measured the RV of $\beta$ Crt: they find it stable at 10–12 km s$^{-1}$, where the difference between individual RVs is not significant, because their error ranges from 2 to 5 km s$^{-1}$. From this, they conclude that the older measurements reported by Campbell & Moore (1928) are erroneous (because they are from different sources) and that $\beta$ Crt and the white dwarf form a wide long–period system or are not physically connected.

We found that this deserved further investigation. First, as Smalley et al. already remark, there is the possibility that their sampling was unlucky, and that $\beta$ Crt is in a highly elliptical orbit, so that the RV is nearly stable most of the time and only in short time intervals changes strongly. Second, to us it seems unlikely that an amplitude of almost 20 km s$^{-1}$ could have been caused by systematic errors in the old measurements. After all, Campbell & Moore report about the careful corrections for possible systematic errors in the different observations. Furthermore, on three occasions two RVs are given for the same date, indicating independent measurements of the same plate. Their differences can serve as a measure for the RV error; they never exceed 2.2 km s$^{-1}$.

## 2. A preliminary period analysis

We used the RVs reported by Campbell & Moore (1928) and Smalley et al. (1997) in a preliminary period analysis. ISDA (Irregularly Spaced Data Analysis; Pelt 1992) gives several possibilities to derive periods from irregularly spaced data. Three different methods gave consistently a period of 7.87 days. Note, that this period is quite short compared to the sampling rate of both the old and the data by Smalley et al. (1997). Since neither of these methods assumes anything about the shape of the phase diagram, it was further encouraging to note that the phase diagram for this period had the shape of an elliptical RV-curve with a sharp minimum (lasting about 0.2 in phase; the RV–curve

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⋆ Based on observations obtained at the 2.0m Ritchey-Chretien-Coudé Telescope of the National Astronomical Observatory, Rozhen, Bulgaria.

with this period has $K$ = 27.5 km s$^{-1}$ and $e$ = 0.62; the typical measurement has $\sigma$ = 2.4 km s$^{-1}$, consistent with the above considerations about the measurement errors). Thus, we decided to observe $\beta$ Crt in an observing run at the Bulgarian National Astronomical Observatory, Rozhen, in May 1997.

## 3. Observations and reductions

$\beta$ Crt has been observed in 6 out of 9 nights in May 1997 at the National Astronomical Observatory, Rozhen, of the Bulgarian Academy of Sciences, using the Coudé spectrograph at the 2m RCC–telescope. The spectra were recorded with the ASTRO–550 system manufactured by Ista Ltd. (Berezin et al. 1991) with a virtual phase 580$\times$520 CCD developed and produced by Electron Corp., St. Petersburg, Russia) (see also Shcherbakov et al. 1995). The camera was provided by the Helsinki University Observatory. The pixel size is 24$\mu$m $\times$ 18$\mu$m. The slit–width was set to 300$\mu$m, so that the FWHM of a typical comparison line is about 2 pixels. The grating 632/22$^\circ\!\!.$3 was used, providing a dispersion of 0.01 nm per pixel. The total length of the recorded spectra is thus about 6 nm. The observed wavelength region is centered at 490 nm; in some nights additional spectra centered at 505 nm were taken. The integration times were between 5 and 10 minutes. The signal–to–noise ratio of the spectra is typically around 150. Due to the position of $\beta$ Crt, observations were only possible very early in the night at very high zenith–distances. The first of our spectra was taken too early, and is heavily contaminated by a superposed solar spectrum.

During observations and reductions the 3A–software package (Ilyin 1993) has been used. The reductions contain the usual steps of bias subtraction, flat–fielding, spectrum extraction and wavelength calibration. The spectrum extraction was done by an algorithm similar to the optimal extraction described by Horne (1986), getting rid of the cosmics at the same time. The wavelength calibration is based on typically 25 Fe and Ar lines, whose wavelengths are taken from the catalogue by Hirata & Horaguchi (1995). The typical error of the dispersion curve (being a polynomial of degree 1) is 0.26 pm, corresponding to 0.16 km s$^{-1}$ at 490 nm.

The external accuracy of the spectra and the reductions was checked using spectra of the Sun (evening sky). One spectrum in each of the two spectral regions was available. The positions of solar absorption lines were measured by approximating them by Gaussians. The line shifts then were computed by comparing with the wavelengths given by Pierce & Breckinridge (1973). The mean shifts from many lines are: +(0.01$\pm$0.12) km s$^{-1}$ and +(0.26 $\pm$ 0.18) km s$^{-1}$ for the spectra at 490 nm and 505 nm, respectively. There are thus no significant systematics, and the main source of RV errors for sharp lined spectra is the error of the dispersion curve.

## 4. The radial velocity of $\beta$ Crt

Smalley et al. (1997) measured the RVs of individual lines, which were then averaged for each spectrum. This procedure was also attempted here. However, the rotational velocity of $v$ sin $i$ = 47 km s$^{-1}$ (Smalley et al. 1997) leads to severe blending which makes identification of the features and assignment of a laboratory wavelength to a certain blend difficult. The result was that in a typical spectrum the RVs of individual lines varied between –10 and +12 km s$^{-1}$. The mean RV also sensitively depends on the subjective choice of what is considered as outlier not to be taken into account in the average. The mean error of the average RV is about 2–3 km s$^{-1}$, similar to what Smalley et al. (1997) report for their RVs. Considering the error and the substantial uncertainty of the laboratory wavelengths of the features, it is surprising that Smalley et al. obtained RVs, which — with only one exception out of 7 measurements — are within 0.3 km s$^{-1}$ around +10.5 km s$^{-1}$.

We therefore decided to use a different method. Adopting the atmospheric parameters obtained by Smalley et al. (1997), i.e. $T_{eff}$ = 9000 K, log $g$ = 3.5 and $v$ sin $i$ = 47 km s$^{-1}$, and assuming solar abundances (consistent with the results of Smalley et al.), model spectra for the two wavelength regions were computed, based on Kurucz (1993) atmospheric models and the atomic line list obtained from VALD (Piskunov et al. 1995). The RVs of $\beta$ Crt are then obtained by cross–correlation of each observed spectrum with the model. The results are given in Table 1.

**Table 1.** The heliocentric radial velocities of $\beta$ Crt obtained by cross–correlation of the observed spectra with a model spectrum. The columns give the heliocentric Julian date (HJD) of mid–exposure, the central wavelength of the spectral region observed, the RV from the cross–correlation, and the weight of the RV used in computing the mean RV.

| HJD –2450000 | Region (nm) | RV (km s$^{-1}$) | weight |
|---|---|---|---|
| 585.2445 | 505 | +9.11 | 0.0* |
| 585.2534 | 490 | +3.36 | 1.0 |
| 588.3203 | 490 | +1.80 | 1.0 |
| 589.3016 | 490 | +1.59 | 1.0 |
| 589.3126 | 505 | +0.05 | 0.5 |
| 589.3178 | 505 | +3.76 | 0.5 |
| 590.2967 | 490 | +3.14 | 1.0 |
| 590.3103 | 505 | +6.36 | 0.5 |
| 592.3032 | 490 | +2.42 | 1.0 |
| 592.3166 | 505 | +0.05 | 0.5 |
| 593.3032 | 490 | +3.86 | 1.0 |

* This spectrum has a strong contamination by a solar spectrum and is not used.

In order to reduce the influence of noise, all spectra were filtered using a Gaussian filter of FWHM=0.03 nm (about 3 pixels). The model spectrum contains the same pattern of blends as the observed spectrum, however, the depths of some features are quite different (mainly the weak features are stronger in the observed spectrum than in the model). For the final RVs in Tab. 1 only those features were taken into account during the cross–correlation whose depths and shapes were similar to those in the observed spectrum. These were 4 strong lines/blends in the 490 nm region and 2 in the 505 nm region; therefore, we introduce a relative weight of 0.5 for all RVs from 505 nm spectra. The first spectrum has a strong contamination by a solar spectrum, which was subtracted during the reduction. The RV from this spectrum, however, is much larger than that from the 490 nm spectrum taken immediately afterwards; the difference is at least twice that met in other cases of two or more spectra taken in the same night (cf. Tab. 1). We therefore decided not to use this RV (weight 0).

By comparing the RVs from spectra taken in the same night, a measure of the RV–error is obtained. Using the weighted standard deviation, the RV error is between 1.1 and 1.5 km s$^{-1}$; this is a factor of 2–3 better than the one obtained from identifying individual lines and averaging, and better by the same factor than the error given by Smalley et al. (1997).

Comparing the RVs in Tab. 1 with each other, there seems to be no systematic: no systematic difference between the two spectral regions and also no systematic behaviour of the RV with time. We therefore computed the weighted mean RV of $\beta$ Crt:

$$< \mathrm{RV} >= +(2.66 \pm 0.50)\,\mathrm{km\,s^{-1}} \quad (\sigma = 1.60\,\mathrm{km\,s^{-1}}), \tag{1}$$

where $\sigma$ is the standard deviation of an individual RV from the mean. It is not significantly larger than the above estimated error of an individual RV; this is another evidence for *constant* RV of $\beta$ Crt during the time span of 8 days.

On the other hand, our mean RV is significantly different from the mean RV reported by Smalley et al. (1997). Of course, before discussing this, we need to look for systematic errors. The analysis of the solar spectra showed that our spectra have no systematic error in the velocity zero point. The main difference is the different methods by which to analyse the spectra. In those cases, where we attempted to identify the individual lines, the mean RV obtained are consistent with the RVs reported in Tab. 1, considering the much larger error of these RVs. If there is a systematic error at all, it is in the opposite direction: the mean RVs from individual lines tended to be *smaller* than the ones from the cross–correlations. The differences in line depths between the observed and model spectra indicate systematic differences between the spectra and the template used in the cross–correlation; however, if the pattern is similar no systematic error in the *position* is expected. To check this, also cross–correlations with other features and with the whole spectrum were done. The RVs are always consistent with those in Tab. 1 within the errors.

We thus conclude, that the RV of $\beta$ Crt is different from the one obtained by Smalley et al. (1997) in Mar.–May 1994 *and* Jan. 1995. Assuming that there is no systematic error in the velocity scale of Smalley et al., the RV of $\beta$ Crt is clearly variable, within a range exceeding the difference between the two mean velocities, i.e. more than 8 km s$^{-1}$, thus confirming the results obtained early this century (Campbell & Moore 1928). The reason for the variability *may* be binarity, but the data obtained so far do not allow to derive a period. The amplitude of the RV variation argues against a very long period, but it must certainly be much longer than 8 days. The period of 7.87 days reported in Sect. 2 must be considered spurious caused by the small number of measurements and the extremely sparse sampling. Since the RVs reported by Campbell & Moore (1928) are between –3 and +16 km s$^{-1}$ and our constant RV is near the minimum and the one given by Smalley et al. (1997) is near the maximum of this range, an unfortunate sampling of an elliptical RV–curve missing the minimum or maximum is also no longer an explanation. Given the considerable brightness of the star, and its chance of being a Sirius–like system, we urge all observers, who have the opportunity, to take spectra of $\beta$ Crt in order to find the cause for the RV variations.

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