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UBV PHOTOMETRY OF P CYGNI IN 1995–1997

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P Cygni (HD 193237, Ia$^+$, B1), along with Eta Car and S Dor, is one of the prototypes of a group of stars now known as luminous blue variables (LBVs). In view of the current stellar models (Langer & El Eid, 1986; Maeder & Meynet, 1987; Langer et al., 1994) the LBV phase is an extremely short – about 10^4 years – but very attractive period in the evolution of the very massive stars with $120M_\odot > M_{init} > 50M_\odot$. During this phase, located close to the Humphreys–Davidson limit at the top of the HR diagram, the stars are highly unstable showing different kinds of photometric (microvariations of $\leq 0\overset{m}{.}2$, moderate variations of 1 to 2^m, eruptions of $\geq 3^m$ etc.) and spectral (temperature, line-profile) variations. Irrespective of the large number of theoretical and observational works, published in the last 15 years, the fundamental question concerning the causes of these variations is still open. It is clear, however, that the only way to come nearer to the understanding of the LBV phenomenon is to gain more and more observational data for as many stars as possible and to analyse them in detail in view of the current theoretical models. In this respect, the works of van Genderen, Sterken and de Groot (1997, 1998) and Sterken, de Groot and van Genderen (1998), devoted to the photometric variability of LBVs in the Galaxy and the Large and Small MCs, are really demonstrative.

UBV photometry of P Cygni was carried out using a single channel photoelectric photometer attached to the 0.6 m Cassegrain telescope of the National Astronomical Observatory, Bulgaria. The stars 36 Cyg (V=$5\overset{m}{.}594$, B=$5\overset{m}{.}642$, U=$5\overset{m}{.}67$) and HR7757 (V=$6\overset{m}{.}48$, B−V=$-0\overset{m}{.}090$, U−B=$-0\overset{m}{.}410$) were used as a comparison and a check star, respectively. The observations cover the period 1995–1997. Comparing the observed photometric characteristics of the check star with the adopted ones we found that the check was systematically fainter by about 0.01 to $0\overset{m}{.}02$ in V and brighter by about 0.03 to $0\overset{m}{.}05$ in U while the B values agreed in the range of $\pm 0\overset{m}{.}01$. The correction applied to the B−V and U−B observational data equals, respectively, $-0.017\pm 0\overset{m}{.}004$ and $-0.038\pm 0\overset{m}{.}007$. The corrected values are listed in Table 1. The accuracy of the given estimates is better than $0\overset{m}{.}01$ in V and B−V and about $0\overset{m}{.}02$ in U−B.

The light and colour curves of P Cygni are shown in Figure 1. According to our data the star seems to have been on average fainter and bluer than it was at the beginning of the current decade (Markova, Scuderi and de Groot, 1998). The overall average amounts to 4.836±0.027 (4.77±0.003), 0.374±0.01 (0.382±0.001) for V and B−V, respectively. The values in brackets refer to the epoch of maximum light, namely 1992 (Markova et al., 1998). The only notable event during our observational run was the rapid decrease in brightness, by about $0\overset{m}{.}145$, between JD 2450267 and JD 2450297. The amplitude of

Table 1: Photometric observations of P Cygni

JD 2440000+	n	V	B−V	U−B
9993.360	2	4.854	0.360	−0.575
9996.416	2	4.823	0.383	−0.566
10267.389	1	4.720	0.383	−0.575
10295.418	2	4.820	0.389	−0.564
10296.470	3	4.851	0.373	−0.532
10297.388	2	4.863	0.380	−0.549
10629.512	3	4.850	0.381	−0.573
10698.330	4	4.851	0.376	−0.576
10702.330	2	4.823	0.370	−0.573
10739.266	1	4.789	0.361	−0.567
10742.250	2	4.820	0.363	−0.579

this variation exceeds the corresponding standard deviation by more than four times and therefore, should be regarded as real. The colour behaviour of the variation in U−B is redder when faint whereas in B−V no significant changes were observed.

The time variations of the effective temperature, T_{eff}, the radius, R_* and the bolometric luminosity, M_{bol}, can be estimated from the photometric data. However, since the absolute values obtained from the analysis of these data are rather uncertain we determined only the relative variations of these parameters. Relative variations in the effective temperature, $\delta T/T_{eff}$, were estimated from the observed values of U−B colour index corrected for interstellar extinction E(B−V)=0.63 (Lamers et al., 1983). To calculate T_{eff} we used the compilations of the intrinsic colours $(B-V)_0$ and $(U-B)_0$ versus T_{eff} for normal supergiants of luminosity class Ia, given by Schmidt-Kaler (Schmidt-Kaler, 1982, for more information see also Scuderi et al., 1994). Relative variations in the bolometric magnitude, $\delta M_{bol}/M_{bol}$, and stellar radius, $\delta R/R_*$, were determined by calculating the corresponding parameters by means of the well known relations

$$\log R_* = -0.2M_{bol} - 2\log(T_{eff}) + 8.46 \qquad (1)$$

$$M_{bol} = m_v + BC + 5 - 5\lg d - A_v \qquad (2)$$

where BC is the bolometric correction, d is the distance to the star, m_v means apparent magnitude in V band and $A_v = 1.95$. BC was calculated by means of a relationship BC vs. T_{eff} for normal supergiants (Schmidt-Kaler, 1982). We adopted d = 1.8 kpc (Lamers et al. 1983). The obtained estimates for the three parameters as a function of time are shown in Figure 2. We see that the effective temperature varies in the range of ±10 per cent while the relative variations in the R_{ast} and M_{bol} are smaller – about 6 and 3 per cent, respectively. Because the precision of the relative variations is about 6, 3 and 2 per cent, respectively, in the T_{eff}, R_* and M_{bol}, we conclude that the first two quantities show real variations while the last one seems to remain constant in the frame of error. In addition, we also found that the rapid decrease in brightness observed between JD 2450267 and JD 2450297 was accompanied by a decrease in the T_{eff} and by increasing the stellar radius.

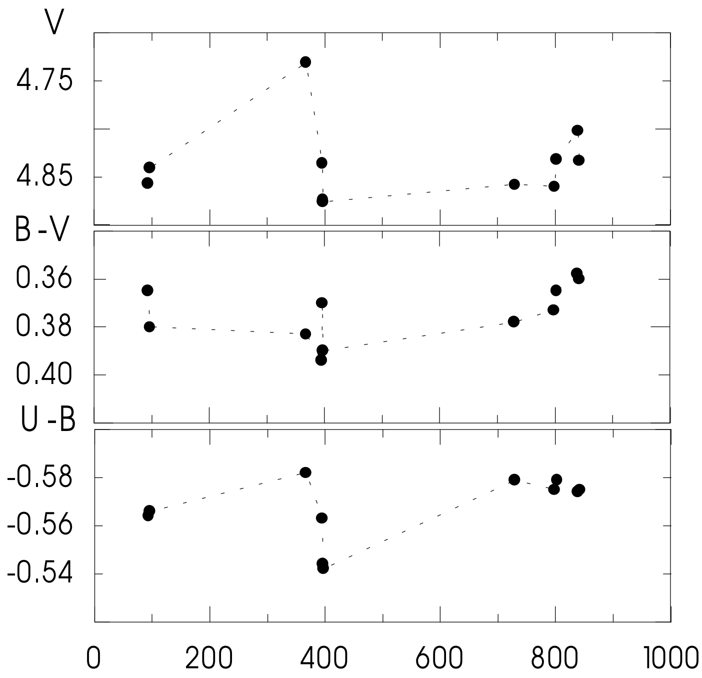

Figure 1. The light and colour curves of P Cygni as a function of time – JD 2449900.

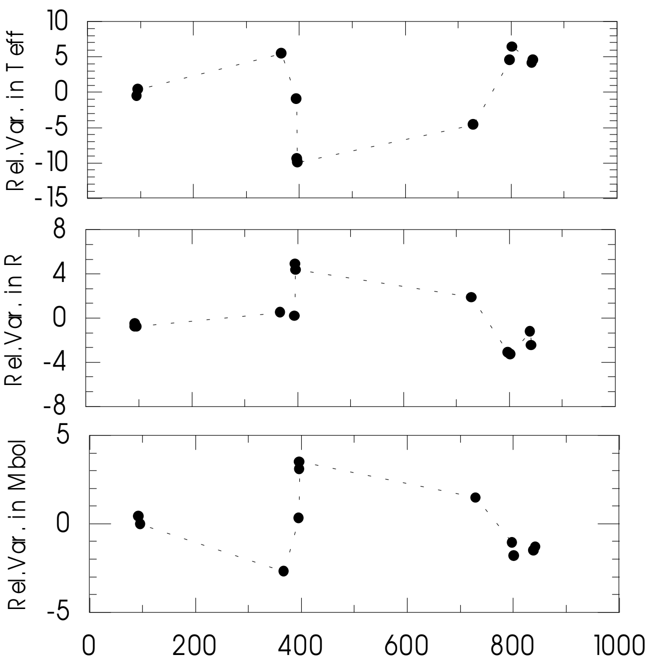

Figure 2. Relative variations in the effective temperature, radius and bolometric luminosity of P Cygni as a function of time – JD 2449900

According to van Genderen et al. (1997, 1998) and Sterken et al. (1998) LBVs show two types of S Dor phases: the very long-term (VLT-SD) and the normal SD phases (colour behaviour redder when brighter). The later are superimposed on the former. Time-scales lie between 1.4 and 25 y. During the SD cycles two types of micro-variations with an amplitude of about $0\overset{m}{.}2$ are present: one near the minima called "α Cyg-type variations" – quasi-periods of 2–6 weeks and colour curves generally blue in the maxima and red in the minima – and the other one near the maxima called "100d micro-variations" – colours generally red in the maxima and blue in the minima. Recently Markova, Scuderi and de Groot (1998) have shown that the photometric behaviour of P Cygni seems to be similar to that of other LBVs. Based on extensive UBV photometry covering the period from 1989 to 1994 the authors found evidence for a long term brightness variation with an amplitude of at least $0\overset{m}{.}1$ that lasts 4.7 years or more. The colour became redder during the brightness increase, at least in B−V, thus suggesting the star exhibited a part of a normal SD phase during that time. Superimposed on this SD phase Markova et al. (1998) observed a number of micro-variations with main characteristics – amplitude of about $0\overset{m}{.}1$ to $0\overset{m}{.}2$, peak-to-peak time scale of three to four months and mixed colour behaviour – more or less similar to that of the "100d micro-variations". In view of the above facts we suggest that during 1995–1997 P Cygni was probably at or near the minima of one SD cycle – the star was fainter and bluer than three years before, namely in 1992 (see Markova, Scuderi and de Groot, 1998). With respect to the rapid decrease in brightness observed between JD 2450267 and JD 2450297 it seems not possible to specify – based on the available data – if this was a descending branch of an "α Cyg-type" or of "100d-type" variation. Nevertheless, the colour behaviour of the variation, at least in U−B, as well as the possibility it has appeared near minimum light suggest classification as of the "α Cyg type".

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