Photoelectric minima of the eclipsing binary PX Cephei

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Abstract. PX Cep is a long amplitude eclipsing binary system of the Algol-type. The primary component is of spectral class A, the secondary is found to be of K [1]. PX Cep is an example for a detached binary system, whose variability was first discovered by Romano (1958). No secondary minimum can be found in the paper of Boninsegna (1985) [2], Borovicka (1995) [3] and Heerlein (1996) [4].
First detection of secondary minimum of PX Cep, detections of primary minimum, Color-Indices (B-V) and (V-R) during occultation and transit, and $(O-C)$ values are presented here. According to hand solution of light curve i present the geometrical elements $r_{s,g}$, the radii for smaller and greater star as fractional parts of their separation a, and the inclination i, the angel between the line of sight and the axis of the orbit.
512 photoelectric observations were taken with an Apogee U16M CCD camera and an apochromatic refracting telescope 130mm f : 9.23. All observations were made at private observatory. The data were acquired in a time span over 168days between 17.06.2013 and 01.12.2013.

1 Measurements

Primary and secondary minimum were acquired in Johnson/Cousins filter band B/V/Rc. All moments of minimums are heliocentric corrected Julian Date HJD. The measurements of primary eclipse (Table 3), secondary eclipse (Table 4) and measurements of the Color-index (B-V) and (V-R) (Table 5) are tabulated. All tables are sorted by the phase p, which can be seen in the last column. The phase p is the decimal part of $(t - t_0)/P$

$$p = \frac{t - t_0}{P} - \left\lfloor \frac{t - t_0}{P} \right\rfloor \mid \lfloor x \rfloor \stackrel{\text{def}}{=} max\,\{k \in \mathbb{Z} \mid k \leq x, x \in \mathbb{R}\} \quad (1)$$

where t is the time of measurement of the star, t_0 is the time of the first observed minimum and $P = 3,126889d$ is the period of the star.

The average errors of all measurements in B/V/Rc are 0.014/0.01/0.032mag.

MPO3J21360625+6554496 has been used as check star for measurements in filter B, V and MPO3J21365362+6551111, MPO3J21353974+6549355 as comparison star, respectively. For measurements in filter Rc the third comparison star was replaced by the star MPO3J21345574+6553455.

2 Light curves

The average magnitude values after primary eclipse between phase 0.1 to 0.4, respectively phase 0.25, in B/V/Rc are 12.389/12.107/11.915mag. The only data after secondary eclipse are measurements between phase 0.78 to 0.85, they shows an average magnitude in B/V/Rc of 12.35/12.078/11.889mag, Δmag between this phases of 0.25 and 0.75 in B/V/Rc are 0.04/0.03/0.03mag. So, the light curve after secondary eclipse in B and V is a little brighter.
The color-index CI between phase 0.3 to 0.35 is 0.289 and between phase 0.78 to 0.85 is 0.273, there is a ΔCI=0.017. So, the light curve after secondary eclipse is little more blue.
The depression of deepest primary eclipse in B/V/Rc in relation to the average brightness value of phase 0.75 are 3.012/2.38/1.917mag. The deepest depression of secondary eclipse in relation to the average brightness value of phase 0.75 are 0.053/0.089/0.121mag. The duration of occultation of the brighter star, so the primary minimum, between first and fourth contact amount to 0.1447d, approximately 9.88h, the secondary minimum requires 0.3514d, appr. 8.43h. Boninsegna (1985) [2] estimated for the primary minimum $\sim$ 8h. Different brightness values on primary eclipses in B/V of 0.1/0.123mag and an increase of the light curves after secondary eclipse indicates active stars and dark or bright spots of one of the two components of the pair.

3 $(O-C)$ values

The following minimums Min ♯1, ♯2, ♯3 (Table. 1) where computed using the program MPO Canopus [8]. Min ♯1 - ♯3 were observed in filter V.

According to the ephemeris of the updated elements of Kreiner (2004) [7]

$$MinI = HJD2452502.3477 + 3.1268701 \times E$$

i calculated following $(O-C)$ values (Table. 1).

Table 1. Observed minimum

Number ♯	HJD	±	Epoch	$(O-C)$
1	2456520.3868	0.000975	1285	-0.0108
2	2456523.5137	0.000975	1286	-0.0107
3	2456592.5920	0.000975	1308	-0.0113

Kreiner (2000) [1] has formed with following epoch an $(O-C)$ graph

$$MinI = HJD2446270.4209 + 3.126966 \times E$$

Table 2 shows the $(O-C)$ values of Min ♯1 - ♯3 based on Kreiner 2000.

Table 2. Observed minimum

Number ♯	HJD	±	Epoch	$(O-C)$
1	2456520.3868	0.000975	3278	0.2282
2	2456523.5137	0.000975	3279	0.2283
3	2456592.5920	0.000975	3301	0.2307

With respect to the elements of Heerlein (1996) [4] the $(O-C)$ value of Min ♯1 is 0.2072 after a cycle of 2033, $(O-C)$ of Min ♯2 is 0.2073 after a cycle of 2034 and $(O-C)$ of Min ♯3 is 0.2087 after a cycle of 2056.

Based to the elements of Boninsegna (1985) [2] i found 0.3362 after a cycle of 3278 for Min ♯1, 0.3363 after a cycle of 3279 for Min ♯2 and 0.3387 after a cycle of 3301 for Min ♯3.

4 Hand solution of the Light curve

From the light curve we obtain the fourth contacts $t_1 - t_4$, expressed by the phase during the contact times p_{t_1} and p_{t_4}, the angel ϕ between p_{t_1} and p_{t_4}

$$\phi_{rad} = \frac{p_{t_1} - p_{t_4}}{2} \tag{2}$$

Next we determine the flux F of occultation and transit

$$F = 10^{-0.4 \cdot M_i - M_B} \tag{3}$$

where M_i is the measured magnitude and M_B is the base magnitude at phase 0.75.

We define $F_{0.75} = U$ as the Flux or light level between the two minimums, F_{oc} and F_{tr} as the light level for the brighter star which is in occultation respectively in transit. According to the normalized light curve, we define the Luminocity of the greater star $L_g = F_{oc}/U$ and the Luminosity of the smaller star $L_s = (U - F_{oc})/U$. Normally for pairs on the main sequence the primary minimum corresponds to a transit, so we can write

$$\frac{U - F_{tr}}{U} = L_g \cdot \left(\frac{r_s}{r_g}\right)^2 \tag{4}$$

If we put $k = \frac{r_s}{r_g}$, where r_s is the radius of the smaller star and r_g the radius of the greater star, we will have

$$k = \sqrt{\frac{(U - F_{tr})}{F_{oc}}} \tag{5}$$

Regarding the two stars as disks during total annular eclipse occurs and we project the orbit as an ellipse in the plane of the sky, we will get

$$cos(i) \leq r_g - r_s \tag{6}$$

where i is the orbital inclination.

If we outline the double star in ground plan (G), it is the plane view, in elevation (A), it is the line of sight, and in side elevation (S) (Fig. 2), the projected separation δ of the centers of the two stars at the phase p_{t_4} (Fig. 2A), respectively p_{t_1}, corresponds to

$$\delta = r_g \cdot (1 + k) \tag{7}$$

We will find a trigonometric equation for the projected separation δ (Fig. 2).

$$\delta^2 = x'^2 + y'^2 = (cos(i) \cdot cos(\phi) \cdot a)^2 + (a \cdot sin(\phi))^2 \tag{8}$$

where $a = 1$ is defined as the separation of the two stars. [5;6]

Using Equation 8, 7, 6 and 5 i calculated the three geometric elements

$$r_g = 0.233$$

$$r_s = 0.173$$

$$i = 86.5°$$

where $r_{s,g}$ are the fractional radii in terms of a

A comparison of hand solution and optimized solution of BM3 [8] can be found in [9]. In calculating this three geometrical elements with such methods, they provides initial estimates for more elaborate analysis.

Table 3. Primary minimum in filter B, V, Rc

HJD B	Bmag	phase	HJD V	Vmag	phase	HJD Rc	Rcmag	phase
			2456592,302671	14,459	0,9992			
			2456520,385610	14,382	0,9996			
			2456523,513168	14,336	0,9998			
2456592,307833	15,369	0,0008				2456523,516761	13,797	0,0010

Table 4. Secondary minimum in filter B, V, Rc

HJD B	Bmag	phase	HJD V	Vmag	phase	HJD Rc	Rcmag	phase
			2456628,258275	12,151	0,4980			
2456559,470152	12,385	0,4991	2456534,455550	12,167	0,4993			
2456628,266192	12,379	0,5005	2456556,346524	12,163	0,5002	2456534,459161	12,007	0,5004
			2456559,475801	12,150	0,5009	2456556,350197	11,993	0,5013
2456603,271051	12,360	0,5069				2456559,480855	11,992	0,5025

Table 5. Color Index (B-V) and (V-R)

avg HJD of B,V	(B-V)	phase	avg HJD of V,Rc	(V-R)	phase
2456592,305252	0,910	1,0000			
2456520,388168	0,887	0,0004	2456523,514965	0,539	0,0004
2456628,262234	0,228	0,4993	2456534,457356	0,160	0,4999
			2456556,348361	0,170	0,5007
			2456559,478328	0,158	0,5017
2456559,480917	0,253	0,5026	2456628,272135	0,147	0,5024
2456603,265681	0,216	0,5052	2456603,263001	0,161	0,5044

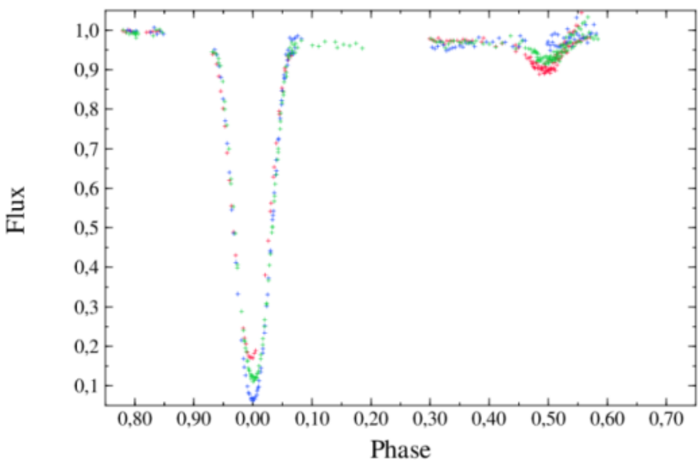

Fig. 1. Normalized Multicolour Light curve of PX Cep

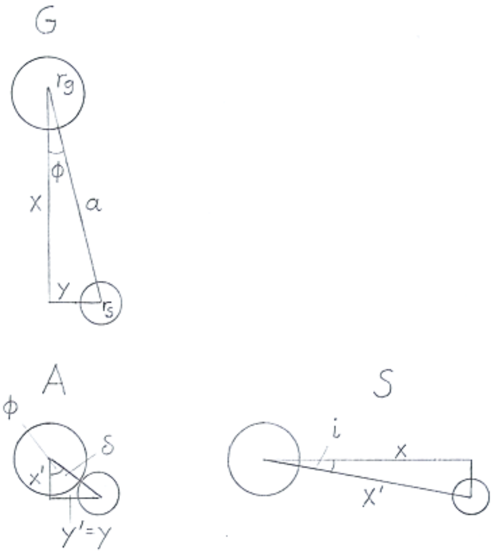

Fig. 2. Outline of an idealized eclipsing Algol system

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