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ON QUASI-PERIODIC BRIGHTNESS VARIATIONS OF P Cygni

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Until recent decades, it was considered that all Luminous Blue Variables are single massive and high luminosity stars. Now for several of them a companion has been found. The opinion exists that P Cygni also has a companion with an orbital period of about seven years. In accordance with this hypothesis a known powerful eruption occurred near the periastron point. P Cygni, as well as several other well-known Luminous Blue Variable (LBV) stars, is so-called "Supernova Impostor" because it survived after powerful outburst. However, there were cases during the last decade, when a LBV star survived after a powerful giant eruption, and then after a few years, explode as supernova. Because the real reason of great eruption and of characteristic light variability of LBV, including P Cygni, not established yet, therefore, any kind of the photometric and spectral observational data are very significant. We present the results of analysis of the long-term photometric observations of hypergiant P Cygni. On the basis of these data, different quasi-periodic brightness changes of the star were revealed.

Key words: *UBV photometry: Luminous Blue Variables: P Cygni*

1. *Introduction*. During last decades many significant findings were done in studying all types of massive stars, including theoretical investigations and model calculations for massive stars' properties in the low metallicity environment (see for example [1]). Massive stars play significant role in the evolution of galaxies throughout the whole history of the universe [2]. The objects, that are on the short-lived transitional phase of evolution and are related either to supernovae impostors or to "real" supernovae, are of special interest. These are massive supergiant and hypergiant stars and so-called Luminous Blue Variables (or LBVs).

Massive hot luminous variable stars, except of WRs, are objects such as η Car, P Cyg, the S Doradus stars and the Hubble-Sandage variables which are on the post main sequence evolutionary stages. In 1984 Conti [3] combined them as LBVs. LBVs are descendants of massive O stars, which are nearly to the end of the core hydrogen burning and during this short stage of evolution they lose their outer layers before becoming WR stars [4]. Observationally, LBVs are cooler than the core-He burning WR stars. The most relatively luminous LBVs are brighter than the horizontal part of the Humphreys-Davidson (HD) limit, but hot enough to not violate the limit. They may be on their first crossing of the HR diagram in a shell H burning or core He burning phase [5]. They undergo episodic mass-loss and probably represent a transition between the most massive O stars and the red supergiants and/or WR stage [6]. They are characterized by large variability of amplitudes and violent mass ejections and, as a rule, have extended atmospheres and high mass loss rates ranging from 10^{-6}-10^{-3} $M_{\odot}$/yr [7].

LBVs are extraordinary massive stars. They can show different type of photometric and spectroscopic variations. The following three types of brightness variability of LBVs are known: 1. Micro-variations with 0.1 mag amplitude and comparatively small time-scale variations from days to weeks or months; 2. S Dor type variations or outbursts with amplitudes of 0.5 mag; 3. Large sporadic outbursts with amplitude >2 mag on a time-scale of a century [5,7].

2. *P Cygni*. P Cygni (34 Cyg) is one of the most luminous stars of the Galaxy with an early B (B1Ia) spectral type. It has been classified as a LBV after two major outbursts in 1600 and 1660. The analysis of historical observations of P Cygni has shown that between 1700 and 1988 its brightness slowly increased by 0.15 ± 0.02 mag/century [7,8].

P Cygni is the nearest LBV, at a distance of 1.7 kpc. Its estimated mass is $30 M_{\odot}$, however, initially it might have had $50 M_{\odot}$ and consequently, about $20 M_{\odot}$ lost during evolution. The effective temperature is $T_{eff} = 18200$ K, the radius is $R = 75 R_{\odot}$, the mass loss rate: $3 \times 10^{-5} M_{\odot}/\mathrm{yr}$, and luminosity $L = 5.6 \times 10^{5} L_{\odot}$ [9,10].

The first spectra of P Cygni, obtained as early as 1897, already showed the famous profile of P Cygni-type spectral lines - an undisplaced emission with a shortward displaced absorption core. Initially this was interpreted as a blend of two different lines. McCrea [11] and Beals [12] were the first who interpreted this feature in the spectra of stars as due to a radially expanding stellar envelope.

Stars with extended envelopes are divided into two broad classes according to the so-called "P Cygni emission line profiles". The first class of stars shows mass ejection or global expansion of the shell. The emission-line structures of such stars are similar to those of P Cygni. The second class of stars is characterized by accretion of material or global contraction of the shell. The structure of their emission lines is inversely compared to the structure of P Cygni emission line profiles. These are referred as "inverse P Cygni profile" objects (Fig.1).

Early serious and detailed analysis of P Cygni spectrum has been carried out by Beals [13], Hutchings [14] and de Groot [15]. In the 1990s, Stahl et al. [16] and Markova [17] have published spectral atlases for P Cygni with identifications

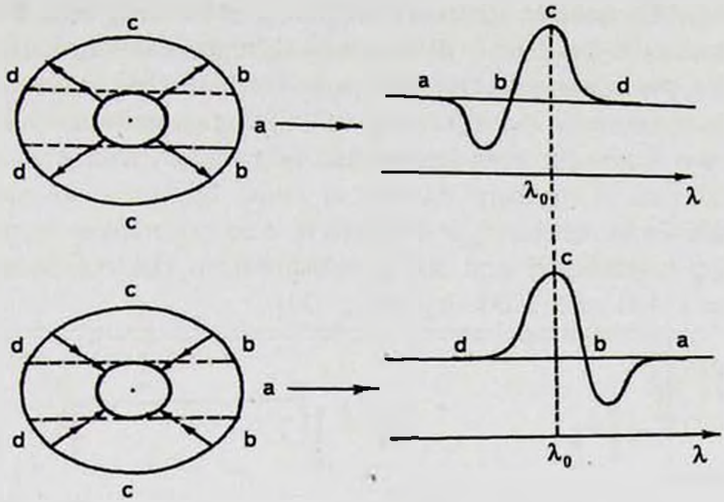

Fig.1. "P Cygni profile" and "inverse P Cygni profile".

of many weak lines in the visual spectral region [7].

P Cygni is located on the upper part of the Hertzsprung-Russell (HR) diagram populated by different types of emission-line stars, including Of supergiants, O3If/WN6, Ofpe/WN9, B[e], LBVs and WR stars. It is clear that all these classes represent different phases in the evolution of stars with zero-age main-sequence (ZAMS) masses of more than $40\,M_\odot$ [7].

A study of the brightness variations of P Cygni between 1985 and 1992/2000 reveals different time-scales, as follows. A long period of the order of 1540 d or 4.2 years is identified as the so-called short S Doradus Phase [18]. A shorter quasi-period of approximately 100 days can be identified quite frequently and is similar to the so called 100-day micro-variations also found in other, similar objects. There is the firm evidence for the presence of a stable period of 17.34 ± 0.1 days with amplitude of not more than 0.1 mag. These variations are identified with the so-called α Cygni-type micro-variations [19]. Their colour behavior is variable: sometimes the star reddens when it brightens; sometimes the star becomes bluer on such occasions.

3. *The data - UBV Observations in the Abastumani Observatory.* The study of variable stars were performed in the Abastumani Observatory from 1932, the year of observatory's foundation. Photoelectric observations of P Cyg were made using the 33 cm reflector of the observatory. The observations were carried out by Nikonov from September 11 up to October 8, 1935 [20]. The amplitude of light variability attained 0.16 magnitudes. Observations of September 7-

November 11, 1936 revealed variation of brightness of 0.10 mag while observations during September 8-October 8, 1937 showed light fluctuations of 0.08 mag.

Nikonov's observations include 758 days. We have clear evidence that the stellar brightness rose by about 0.3 mag (0.298) during approximately one year and then it has almost the same level of 0.08 magnitudes fluctuations during two observational runs. Two sharp minima of stellar brightness are clearly seen $HJD_{min}=2428074.83$ and $HJD_{min}=2428449.34$. Also two maxima moments were fixed: $HJD_{max}=2428444.31$ and $HJD_{max}=2428480.26$. The corresponding time intervals are 374.51 and 35.95 days Fig.2 [21].

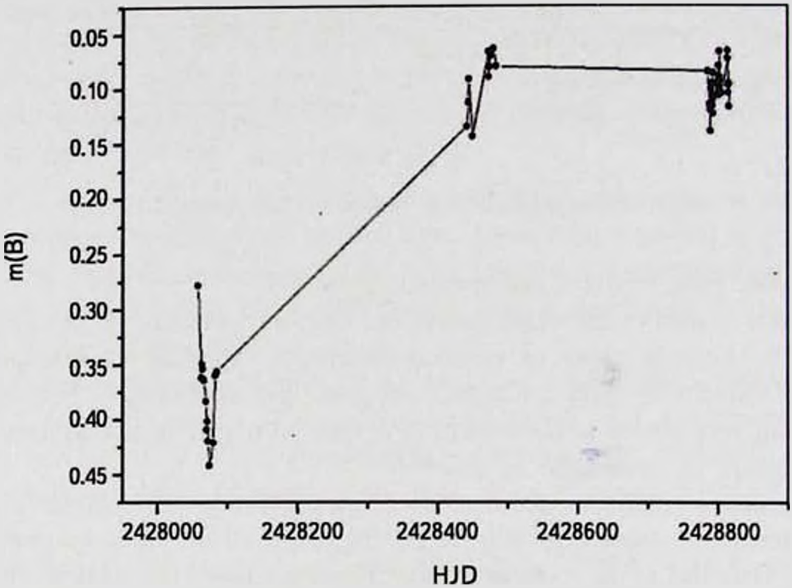

Fig.2. Observations of P Cygni made by Nikonov during 1935-1937, using the 33 cm reflector of the Abastumani Observatory.

The further observations of P Cygni were carried out during 1951-1983 by Kharadze and Magalashvili. We found their original observations of P Cygni in the archives of the Abastumani Observatory. Initially they used 29 Cygni as a comparison star and all observations of P Cygni were processed using this star. The only observations that have been published in the Bulletin of the Abastumani Astrophysical Observatory in 1951-1955. The archives contain whole sets of observational data, not only of P Cygni and 29 Cygni but, in the majority of cases, also those of 36 Cygni. So all data were recalculated (where it was possible) using 36 Cygni as a comparison star [21]. We are presenting plots of UBV light curves of the variable. B and V filters were used during 1951-1960 and then, after

1961, U, B and V filters instead. On the basis of these above-mentioned observations, Magalashvili and Kharadze made conclusion that the behavior of the star was similar to W UMa variability, with the period of 0.500565 d and the amplitude of 0.10-0.08 mag [22]. The article gained great attention from the investigators of variable stars, but the short-term variability was not confirmed [23-25].

Presumably, one of the reasons of Magalashvili-Kharadze erroneous conclusions is the complex variability of this interesting star. It is possible that the variability

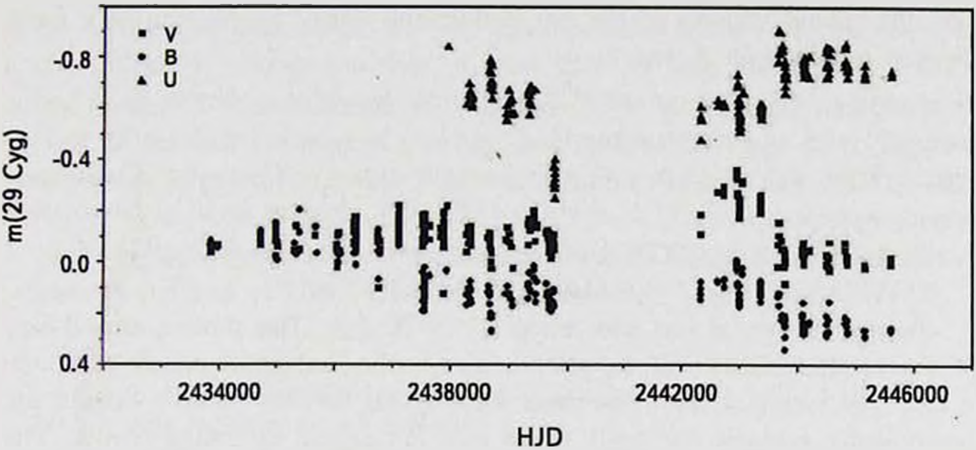

Fig.3. UBV observations of P Cygni made by E.Kharadze and N.Magalashvili during 1951-1983. 29 Cygni = HD 192640 used as a comparison star.

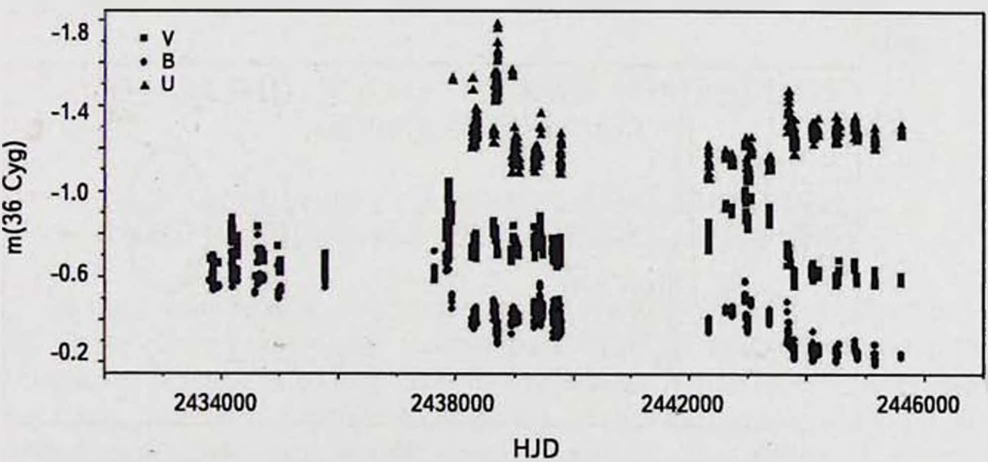

Fig.4. UBV observations of P Cygni made by E.Kharadze and N.Magalashvili during 1951-1983. 36 Cygni = HD 193369 used as a comparison star.

of 12-14 hours is really exists. Brightness reduction of the variable P Cygni occured in two different ways:

1. using 29 Cyg which in its turn is a variable of the δ Sct type. Fig.3 demonstrates brightness variations of P Cygni using 29 Cygni as a comparison star [26].

2. we calculated difference of brightness of variable and 36 Cyg and are giving these UBV data on Fig.4.

At first glance we can see that during 1974-1983 years the star was dimmed in U band while brightened in the B and V bands (the last third part of the Fig.4). The middle part of the figure represents time interval of 1961-1967 and here the colour behavior of the star is different: during brightening in V band the star is fainter in B and U.

4. *Quasi-periods of P Cygni*. So, we have two sets of time series of P Cygni: 1. 29 Cyg (HD 192640) was used as a comparison star, and 2. 36 Cyg (HD 193369) was used as a comparison star. Consequently, the following quasi-periods were found:

1. (1480 ± 31) days; (736 ± 27) days.
2. (1123 ± 36) days; ~579 days and ≈ 128.7 days.

Short quasi-period was also revealed ~15-18 days. This shortest-period may be due to the pulsation of the star, similar to the non-radial pulsations of the α Cyg-type variables. Most luminous stars, which have 20-70 solar masses, are pulsationally unstable for both radial and low-degree nonradial modes. The pulsation driving is by both the high iron line opacity (150000 K) and the helium opacity (30000 K) Kappa effects. These periods range is from 5 to 40 days [27,28].

As for the long-period variability, it may be due to the binarity of the star [29,30]. Kashi published a reasonable hypothesis that P Cygni should have a

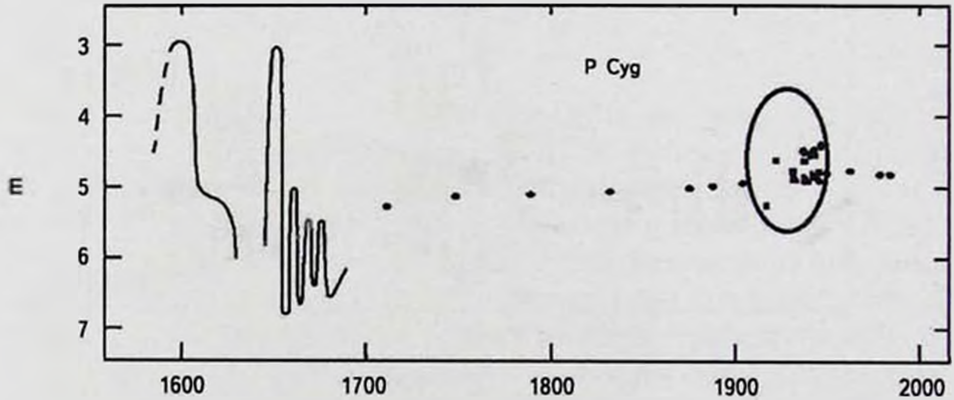

Fig.5. The light curve of P Cygni during 1600-2000 AD by de Groot [39] with Abastumani data in big oval: Rectangles - V filter, right triangles - B and diamonds - U.

companion star with orbital period of ~7 yrs [31].

5. *Discussion*. On the basis of historical observations of P Cygni, it is shown that between 1700 and 1988 its overall brightness slowly increased by 0.15±0.02 mag/century [8,32], but interesting and valuable light variations were found with use of photometric data obtained in Abastumani. Particularly, 0.3 mag brightness increase was observed during 1935-1936 by Nikonov. It indicates that the star unusually changed its brightness (the mean amplitude of its variability is 0.1 mag. In addition of that, we also are presenting UBV light curves of the star. We think that unpublished observations of P Cygni obtained by Kharadze and Magalashvili at the Abastumani Observatory are very significant due to the following reasons: 1. they represent homogenous data of more than 30 years and it was possible to find quasi-periods in brightness variations; 2. There are UBV observations and we can trace colour behavior of the star; 3. The observations by Kharadze and Magalashvili are unique because they are the only existing data of P Cygni observed using filters between 1951-1983 (see Fig.5) [33,26].

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О КВАЗИПЕРИОДИЧЕСКИХ ИЗМЕНЕНИЯХ ЯРКОСТИ P Cygni

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До последних десятилетий считалось, что все яркие голубые переменные (ЯГП) являются одиночными массивными звездами высокой светимости. Теперь для нескольких из них найдены компаньоны. Существует мнение, что у P Cygni также есть спутник с орбитальным периодом около семи лет. В соответствие с этой гипотезой известная Великая вспышка произошла вблизи точки периастра. P Cygni, также как несколько других известных ЯГП звезд, является так называемой "псевдосверхновой", потому что она "выжила" после

Великой вспышки. Однако в течение последнего десятилетия были случаи, когда ЯГП звезда выжила после мощной Великой вспышки, а затем через несколько лет взорвалась как сверхновая. Поскольку реальная причина Великой вспышки и характерной переменности ярких голубых переменных, в том числе P Cygni, еще не установлена, поэтому любые фотометрические и спектральные данные наблюдений о них существенны. Мы представляем результаты анализа долгосрочных фотометрических наблюдений гипергиганта P Cygni. На основе этих данных были обнаружены различные квазипериодические изменения яркости звезды.

Ключевые слова: *UBV-фотометрия: яркие голубые переменные: P Cygni*

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