Optical properties of symbiotic X-ray binary V2116 Oph

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We present optical I band observations of symbiotic X-ray binary GX 1+4 (V2116 Oph) made by the OGLE IV project. The source shows quasi periodic light variations with characteristic time period between subsequent light maxima in the range of 50–75 days. Power spectrum analysis shows a maximum at frequency $\nu = 0.003384 \pm 0.000771\,\mathrm{d}^{-1}$, corresponding to the period $\mathrm{P} = 295 \pm 70\,\mathrm{d}$. Our data can not confirm 1161 day periodicity, since its period is comparable with the total length of our time series. We do confirm 304 days periodicity, previously reported on the basis of the BATSE X-ray data. We also detect the peak in the power spectrum at $\nu = 0.016812 \pm 0.000843\,\mathrm{d}^{-1}$, which corresponds to the period of $\mathrm{P} = 59 \pm 3\,\mathrm{days}$.

1 Introduction

X-ray source GX 1+4 was discovered by Lewin, Ricker and McClintock in 1971 (Lewin et al., 1971) during balloon mission observing the Galactic Center. Authors reported also periodic va-riation of the X-ray flux, with approximate frequency of 1 cycle per 2.3 minutes. Later observations confirmed that GX 1+4 is a pulsar with the spin period $\mathrm{P}_{spin} \approx 123.5$–$125.5\,\mathrm{s}$ (Galloway et al., 2001), which is powered by the accretion (Glass & Feast, 1973; Davidsen et al., 1977; Chakrabarty & Roche, 1997). Davidsen et al. (1977) classified this source as symbiotic X-ray binary (SyXB), containing M6 giant and the neutron star instead of a white dwarf – it was a first identification as SyXB. Based on the presence of TiO and VO bands, Shahbaz et al. (1996) changed the classification of giant star in this source to M5.

Different orbital periods in GX 1+4 were determined. Orbital period of about $\mathrm{P}_{orb} \approx 304$ d was reported by Cutler et al. (1986), based on high energy data from OSO-8. This result was improved by Pereira et al. (1999), who obtained $\mathrm{P} = 303.8 \pm 1.1\,\mathrm{d}$ and suggested, that this periodicity could be most likely the orbital period. They also argued, that since giant fills its Roche lobe, the neutron star accretes matter by Roche lobe overflow. Based on the infrared spectroscopy, Hinkle et al. (2006) obtained orbital period $\mathrm{P}_{orb} = 1161 \pm 12\,\mathrm{d}$. These results were questioned by Corbet et al. (2008). Authors did not find long periodicities in Swift data.

2 Observations and results

In this paper we present unprecedented long term and very accurate optical observations of symbiotic X-ray binary GX 1+4 (V2116 Oph), obtained by OGLE IV

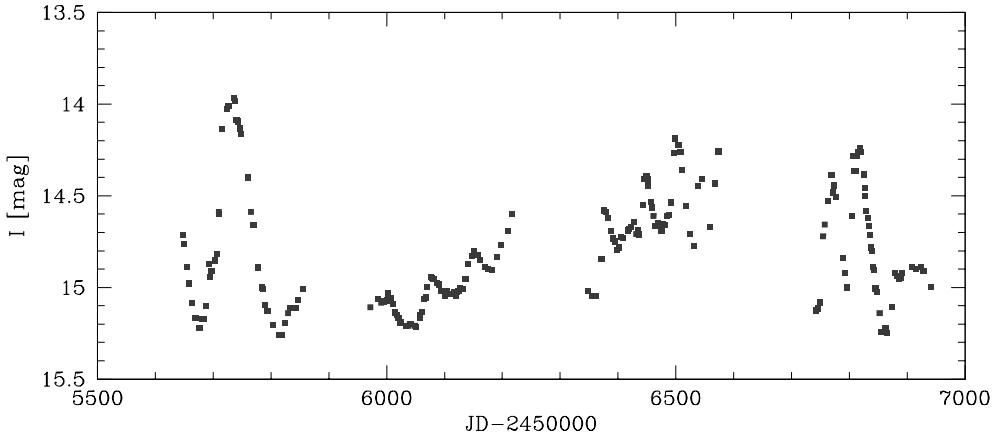

Fig. 1: Light curve of V2116 Oph from OGLE IV data, obtained in I filter from 8th July, 2010 to 12th October, 2014. Typical error of I brightness equals 0.005 mag and is smaller than the size of a single point in the light curve.

project during monitoring of the Galactic Bulge. OGLE IV is a fourth phase of the Optical Gravitational Lensing Experiment, started in 1992 in Las Campanas Observatory (Udalski et al., 1992). Since 1997 OGLE project uses its own 1.3 m telescope. From 2010 the project undergone next upgrade (OGLE IV), and the new telescope is equipped with a large mosaic camera, consisting of 32 CCDs with 1.4 deg^2 field of view. Comprehensive description of the instrumentation of the OGLE IV can be found in Udalski et al. (2015). Observations cover over 3000 square degrees in the sky, mostly the densest stellar regions, including the Galactic Bulge and the Magellanic Clouds. OGLE IV was designed to extensive study of gravitational microlensing events, extra solar planet search, and studies of variable stars, and it monitors regularly over a billion different type sources.

Figure 1 shows the I filter light curve of V2116 Oph, obtained from OGLE IV data. Observations of this object cover 1558 days (about 4.27 years), from 8th July, 2010 to 12th October, 2014. V2116 Oph is a very well known X-ray source, but optical data were very scarce so far, so our observations give rare occasion to study long term optical behaviour of Symbiotic X-ray Binary. What is characteristic in the light curve of this binary the numerous brightenings of this source take place every several dozen of days. These events are not strictly periodic and have different amplitudes. Three of them exhibit amplitude of at least 1 mag (see Fig. 1), the remaining ones usually have less than 0.5 mag. In our opinion high amplitude brightenings could be caused by different mechanism than those of low amplitude. The latter brightenings are seen only in the central part of the light curve, which we analyse separately.

Table 1 contains a list of low amplitude maxima, with time moments and time intervals between them. Figure 3 shows the central part of the light curve, between 2 455 900 and 2 456 600 JD. Time elapsed between subsequent maxima ranges from about 50 days up to 75 days, but the first three intervals seem almost equal. The latest one is substantially shorter (see time intervals marked by double arrows in Fig. 3). It could be caused by changes in the accretion rate.

In light minima object also has different brightness. In some cases the source is brighter after the burst than before it. It seems that if the source is bright, then bursts have lower amplitude, and in opposite, high amplitude brightenings take place

when the source is relatively dim.

In the light curve of V2116 Oph obtained from the OGLE IV data we searched for a periodicity using the AoV code (Schwarzenberg-Czerny, 1989). We searched for very long time periodicity as well as for the periodicity in one day scale. We used standard AoV algorithm with an option, which determines optimal step of the frequency during calculation of the periodogram. AoV algorithm calculates the following variables:

$$(r-1)s_1^2 = \sum_{i=1}^{r} n_i(\bar{x}_i - \bar{x})^2, \tag{1}$$

$$(n-r)s_2^2 = \sum_{i=1}^{r}\sum_{j=1}^{n_i} (x_{ij} - \bar{x}_i)^2, \tag{2}$$

where: n is the total number of observations, r – number of bins, $\bar{x}$ – the average of all observations, $\bar{x}_i$ – the average of magnitudes in i-th bin.

The Θ statistics is defined as the ratio:

$$\Theta_{AoV} = s_1^2/s_2^2. \tag{3}$$

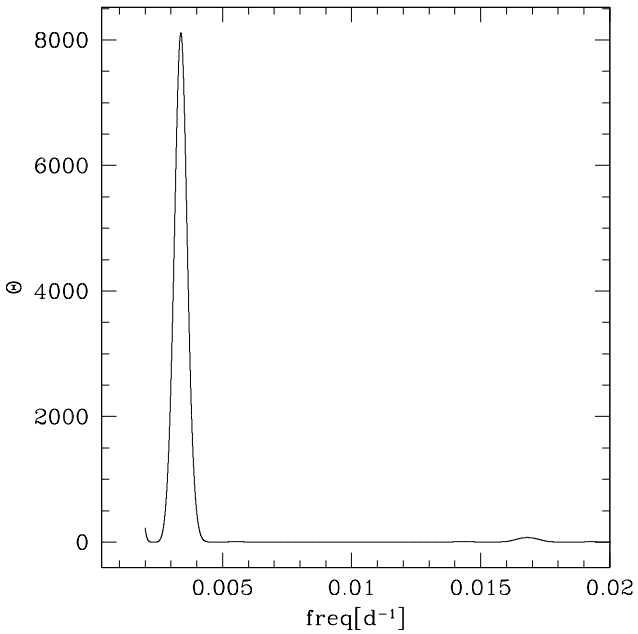

Fig. 2: Power spectrum of V2116 Oph obtained from the central part of the OGLE IV data using AoV algorithm in the most important part of our frequency range. The peak is at the frequency $\nu = 0.003384 \pm 0.000771\,\mathrm{d}^{-1}$, which corresponds to the period $\mathrm{P} = 295 \pm 70$ days. We also detect the secondary peak in the power spectrum at $\nu = 0.016812 \pm 0.000843\,\mathrm{d}^{-1}$, which corresponds to the period $\mathrm{P} = 59 \pm 3$ days.

We analysed the central part of the light curve, shown in Figure 3, between 5971 and 6573 days. In our analysis we rejected time period 5600–5900 and 6700–7000 days. The reason of that is our inability to discuss the single peak in the light curve, which occurred at about 5735 d. Central part of the light curve shows a specific

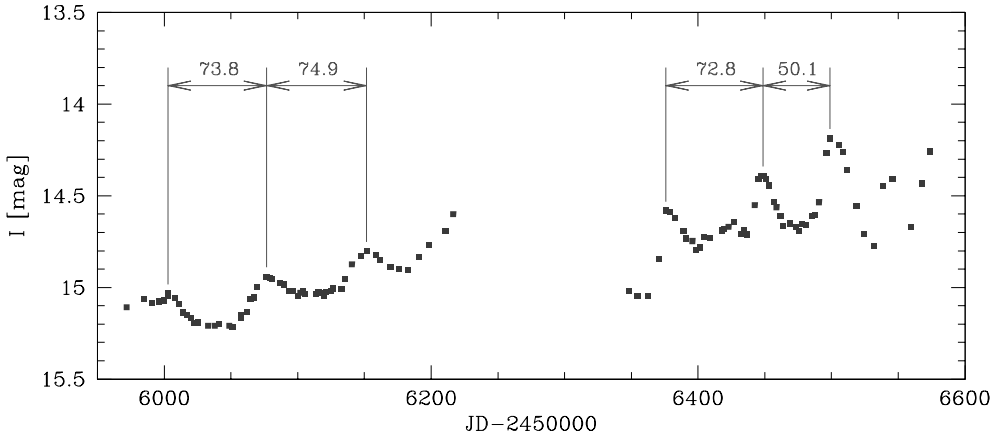

Fig. 3: The central part of the light curve of V2116 Oph, obtained in I filter from OGLE IV data. Typical error of I brightness equals 0.005 mag, and is smaller than the size of a single point in the light curve.

pattern of light oscillations, which can be analysed in the frequency range of 0.002–0.1 d^{-1} (periods from 500 to 10 days). In our opinion the leftmost brightenings have unexplained origin, and may not be related to the orbital or oscillation period.

Figure 2 shows the relevant part of the power spectrum of GX 1+4. The most prominent peak occurs at frequency $\nu = 0.003384 \pm 0.000771\,\mathrm{d}^{-1}$, corresponding to the period $\mathrm{P} = 295 \pm 70\,\mathrm{d}$. This value is in an agreement with values of the orbital period, obtained by Cutler et al. (1986) and Pereira et al. (1999). However, we should stress here that there is a gap in the central part of the optical light curve, which divides analysed time period onto two parts, lasting approximately 300 days.

In the power spectrum we also found other, much smaller peak at frequency $\nu = 0.016812 \pm 0.000843\,\mathrm{d}^{-1}$, which corresponds to the period $\mathrm{P} = 59 \pm 3$ days. Note, that the peak is weakly visible in periodogram, presented in Fig. 2, but the corresponding light variations in I filter are clearly seen in the Fig. 3. Probably it is some kind of an average period between the brightenings mentioned above.

Table 1: List of maximum brightness timings in the central part of the OGLE IV V2116 Oph light curve.

Time	I [mag]	Interval
6002.85347	15.033	
		73.82799
6076.68146	14.941	
		74.90365
6151.58511	14.802	
6375.78837	14.582	
		72.83132
6448.61969	14.391	
		50.07819
6498.69788	14.185	

3 Conclusions

In this paper we present long and very accurate optical observations of the symbiotic X-ray binary V2116 Oph (GX 1+4), obtained in I filter by the OGLE IV project between 8th July, 2010 and 12th October, 2014. The observations cover 1558 days (about 4.27 years). In that time period the source underwent several brightenings, showed in Fig. 1, lasting a few dozen days. These outbursts have different amplitudes and are not strictly periodic. It seems that two types of outbursts are present in the light curve: with amplitude exceeding 1 mag and with amplitude usually less than 0.5 mag. In our opinion these two kinds of brightenings could be caused by different mechanisms. The interval between small amplitude brightenings ranges from ~ 50 days up to 75 days (Fig. 3). Probably there is no regularity in this sequence of the brightenings. They are likely caused by changes in the accretion rate.

Probably for this reason the power spectrum, generated by Analysis of Variance (AoV code, Schwarzenberg-Czerny 1989) has shown only a small peak at frequency $\nu = 0.016812 \pm 0.000843\,\mathrm{d}^{-1}$, which corresponds to some kind of the average period $\mathrm{P} = 59 \pm 3$ days. In the periodogram we also found the prominent peak about the frequency $\nu = 0.003384 \pm 0.000771\,\mathrm{d}^{-1}$, corresponding to $\mathrm{P} = 295 \pm 70$ d, which is in an agreement with values of the orbital period, found by Cutler et al. (1986) and Pereira et al. (1999). Although we have to be careful because of interseasoned incompleteness of the optical light curve of V2116 Oph.

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