STUDIES OF X–RAY NOVAE IN THE CRIMEAN ASTROPHYSICAL OBSERVATORY

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The regular TV and CCD optical monitoring of the five X-ray novae (QZ Vul, V404 Cyg, V518 Per, J2123-058 and J1859+226) has been carried out in the Crimean Astrophysical Observatory. We made observations both immediately after announcement of the optical identification during the outburst decline and in a faint quiescent state in the close cooperation with colleagues from Russia, Spain, UK, and Japan. The review of campaign's achievements (discoveries of orbital and "superhumps" periods, quasi-periodic phenomena, studies of the nature of the binaries components) is presented.

INTRODUCTION

The X-ray novae or soft X-ray transients are a subclass of low-mass X-ray binaries. They are characterized by episodic X-ray outbursts lasting for several months. Their luminosity can increase by as much as a factor of 10^7, see [1]. Similar to the novae stars, X-ray novae show fast rise and slow exponential or linear decay. These objects are very promising targets in the field of searching for the neutron stars and black holes in the close binaries. Since the discovery of the first X-ray nova V616 Mon in 1975 there are currently 11 known X-ray novae with 8 black holes and 3 neutron stars as a primary components. The secondary star is the late-type star in such systems. Over more then ten years the optical studies of some X-ray novae have been carried out in the Crimean Astrophysical Observatory in the frame of international multilongitude campaigns. All our photometry was done at the TV complex of 0.5-m MTM-500 meniscus telescope [2] and at the 0.38-m Cassegrain telescope with SBIG ST-7 CCD camera [3]. Here we present a review of the main results of these campaigns.

QZ VULPECULAE = GS 2000 + 25

QZ Vul = GS 2000 + 25 was discovered in the X-ray outburst by the All Sky Monitor on the board the Ginga satellite telescope in 1988 [4]. We started our TV photometric monitoring immediately after announcement of the optical identification, when the brightness of nova was near ($B = 18^m$) and finished, when it reached $B = 19^m$. Our previous analysis of the 104 observations on 15 nights yields gives the existence of light variations with one of suspected periods (with 1-day aliasing): $0\overset{d}{.}532$, $0\overset{d}{.}348$ and $0\overset{d}{.}258$ [5]. Later we combined our data with CCD data obtained by Casares and Kidger at 1m JKT telescope on La Palma and found the period $0\overset{d}{.}347$ to be a real one that is close to one of our determinations. We suggested that these light variations display the possible superhump period similar to those of the SU UMa stars during the superoutbursts [6, 7].

Now QZ Vul is known as the X-ray nova that contains the black hole of 5.3–8.2 $M_\odot$ as the primary component [8].

V404 CYGNI = GS 2023+338

The X-ray nova V404 Cygni was also discovered by Ginga satellite during the 1989 outburst [9] and was identified with a known recurrent nova. Soon it was discovered as the strong black hole candidate by Casares *et al.* [10] from spectroscopic investigations: the mass function of V404 Cyg was found to be equal to 6.08 $M_\odot$. In 1991 in order to study V404 in the low brightness state we undertook a campaign on the photometric monitoring (CrAO, MTM-500) with spectroscopic observations (La Palma, 4.2-m William Hershel Telescope) simultaneously. The system that star was already in a quiet state ($B = 19^m$). Our observations shown the same period as the spectroscopic one (6.5 days) that was interpreted as the orbital period. The photometric light variations here are explained by the considerable ellipsoidal distortion of the secondary component caused by the massive primary component. The results of that campaign were the determination of the parameters of binary [11, 14] system: inclination $i = 45 - 70$, mass ratio $q = 4.5 - 2.6$, orbital separation of the components

$a = 46 - 39Ro$. The mass of the black hole was estimated of about 27–14 $M_{\odot}$ that later was defined more precisely by Shahbaz *et al.* as $\sim 12M_{\odot}$, [15].

Our long-term monitoring of V404 in quiescence yields the variations of ellipsoidal light curve from year to year that could be caused by some variations in accretion disk structure (may be, size) with time. Besides of the orbital variability, V404 Cyg also displayed 0.24 d quasi-periodic optical variations. We found that this phenomenon is persistent from year to year, however, the amplitude sometimes drops from $0\overset{m}{.}14$ to the less than $0\overset{m}{.}03$ [12, 13]. The source of these variations could be localized in the inner accretion disk surrounding the black hole and connected with some non-stationary accretion process.

V518 PERSEI = GRO J0422+32

This X-ray nova was first detected by the Burst and Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory in 1992, Aug. 5 [16]. Since Aug. 11 the source has been observed by the all-sky X-ray WATCH monitor on the GRANAT satellite [17]. The optical counterpart was discovered at the TV complex of MTM-500 in the Crimean Astrophysical Observatory as the blue star of $13\overset{m}{.}1$ [18]. It was done after visual inspection of each of the 36 fields that covered the whole 60' WATCH error box and after comparing with the corresponding Palomar Sky Survey plate. We have undertaken the simultaneous UBVR observations during the first 100 days after the outburst and found that the optical light has decayed at a rate of 0.0065 mag/day [19]. Similar to QZ Vul in the outburst decline, V518 Per also displayed the SU UMa-like superhumps (5.1 h) that were discovered by Kato [20]. At present time V518 Per is also known as the black hole candidate among X-ray novae. Casares *et al.* have found the mass of compact component is to be equal to 2.5–5.0 $M_{\odot}$, see [21].

XTE J2123-058

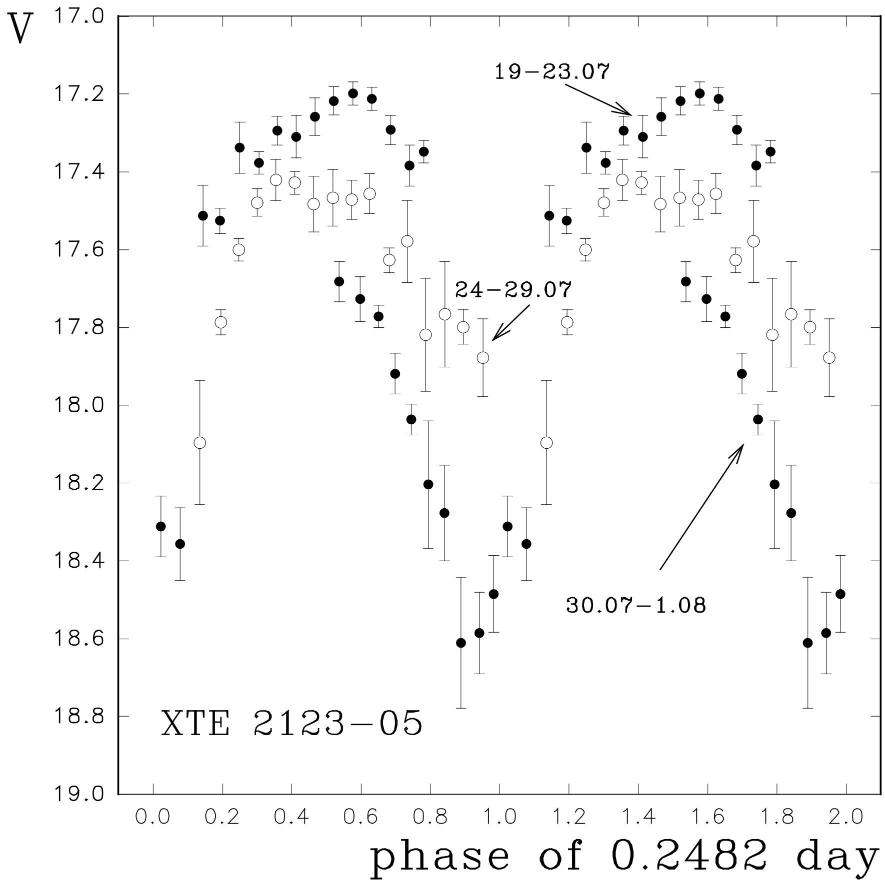

Figure 1: Fast evolution of the orbital lightcurves of XTE J2123-058 during 10 days of the outburst. The mean lightcurves that are averaged within three data sets are shown by arrows

The X-ray nova J2123-058 was discovered in 1998 by the Rossi X-Ray Time Explorer (RXTE) satellite [22]. The optical counterpart was identified with a star of $R = 17\overset{m}{.}2$ by Tomsick *et al.* [23]. The optical observations of this nova have been carried out at IAC80 and 1-m Optical Ground Station (OGS) in the Observatorio del Teide (Tenerife); at 0.5-m amd 0.38-m telescopes in the Crimean Astrophysical Observatory; at 1.25-m telescope in the Crimean laboratory of Sternberg Astronomical Institute; at the 1-m telescope Mount Canopus in Tasmania and at the 1.2-m telescope at the Kryonerion Astronomical station of the National Observatory of Athens at Kryonerio of Korinthina.

The dense runs of observations allowed us to study the evolution of light modulation during the various stages of the outburst. It was shown that at the first stages the nightly partially eclipsed lightcurves were modulated on the $5^h_{\cdot}95$ orbital period that exhibited growth of amplitude with time (up to $1^m_{\cdot}4$). The evolution of the orbital light curves during one month are shown in Fig. 1. They are constructed for the data obtained at the TV complex of 0.5-m telescope. This variability was explained by a strong X-ray heating of a secondary component and accretion disk surrounding a primary one. The change of the lightcurves shape and amplitude was consistent with shrinkage of disk during the course of outburst [24]. One of the most significant result of our campaign was the detection of the rapid switching-off the X-ray heating. At least in 10 days the observed high-amplitude light modulation was disappeared and replaced on the typical two-humped ellipsoidal light curves with amplitude of $0^m_{\cdot}4$. It happened just when this system has reached the quiet state.

XTE J2123-058 is believed to have a neutron star rather than a black hole as a compact component [25, 26].

XTE J1859+226

In 1999 Wood *et al.* reported the discovery of another new X-ray nova [27] XTE J1859+226 by RXTE. They found that the energy spectrum and its characteristics are reminiscent of a galactic black hole candidate. Garnavich and Stanek [28] detected of an optical counterpart to this transient as the star of $R = 15^m_{\cdot}1$. It was found also [29] that this source shows the relativistic radio jet ejections.

Together with Japanese colleagues from Kyoto University we have undertaken the photometric observations in order to study the outburst decay and to search for possible periodicity. We found the light modulation with 6.47 hours soon after the start of the outburst, see [30]. However, neither this period was confirmed, nor another periodicity was found later.

Together with colleagues from Spain and UK we continued a monitoring of this nova over all outburst decay. The results of this campaign are in preparation.

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