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Detection and Study of a Number of Transients on Telescopes of the MASTER Global Network and MASTER OT J044907.58+705812.7 as an Example

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Abstract—In this paper, details of the detection of new object MASTER OT J044907.58+705812.7 (AT2024aaf) discovered on January 14, 2024 during a regular survey using the MASTER-Tunka telescope of the MASTER Global Network of Moscow State University have been present. Additional photometry of the object during joint observations at AZT-11 and 2.6-m ZTSh telescopes of CrAO RAS, MASTER-Tunka, and MASTER-Kislovodsk telescopes has been obtained. Large amplitude ($>7^m$), blue color at maximum, brightness fluctuations during the flare with a characteristic time of ~0.06 days, long (at least 50 days) return to a calm state, the presence of at least four repeated rebrightenings gives grounds to classify the object as a dwarf nova of the WZ Sge type with multiple rebrightenings. In the paper, details of the detection of flares of other dwarf novae: MASTER OT J195416.74+494421.1, MASTER OT J150719.46–283114.9, MASTER OT J185835.32–354042.2, MASTER OT J174714.38+150048.1, and MASTER OT J065054.42+593625.5 as an example of the operation of software for processing wide-field images and identifying new and variable sources in them in real time have also been provided.

Keywords: cataclysmic variables, dwarf novae, WZ Sge type stars, transients, robotic telescopes, MASTER OT J044907.58+705812

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1. INTRODUCTION

Dwarf novae are a subclass of cataclysmic variables (CVs) that exhibit regular flares. They are distinguished from other CPs by the regularity of the rapid increase in the brightness of the source that is caused by the existence of an accretion disk. Dwarf nova flares occur in binary star systems, where one component is a non-magnetic white dwarf that is accreted from a neighboring low-mass star filling its Roche lobe [1–6]. The rate of mass loss by the secondary component is significantly higher than the rate of accretion onto the white dwarf, so matter accumulates in the accretion disk, heating it. When the critical temperature is reached, the viscosity of the substance changes abruptly, due to which the angular momentum begins to be effectively transferred to the outer edge of the disk, the accretion rate increases, and a flare occurs. After this, the radius of the accreting disk typically increases, the temperature drops, the viscosity decreases, and the accretion rate slows. This process can occur with a frequency ranging from several days to several decades [7–10].

Depending on the type of accretion, its rate, the distance between the components, the magnitude of the magnetic field, the spectral class and chemical composition of the neighbor, the increase in the brightness of the system due to processes in the accretion disk around the white dwarf is observed with different characteristics (period, amplitude, and color characteristics). One of the most significant correlations—the larger the amplitude of the flare, the longer the period between them—confirms that the flares originate from matter accumulated over a long period of accretion.

CVs with orbital periods from 76 min to 3.18 h [11] belong to the SU UMa-type dwarf novae [12]. Their defining feature is two types of flashes: "normal" and "superflares." During superflares, so-called superhumps—fluctuations in brightness with a period several percent greater than the orbital period are observed. A special group of SU UMa type stars are dwarf novae of the WZ Sge type. They are characterized by a large flash amplitude (6^m–8^m against 2^m–5^m in ordinary SU UMa-type stars), rare appearances (decades), the shortest orbital periods among SU UMa type stars (in most cases shorter than 0.06^d), and a long return to a calm state.

In recent years, several thousand transients, of which about half are outbursts of dwarf novae [17], have been discovered using the robotic telescopes of the MASTER Global Network of Moscow State University in a fully automatic mode, thanks to software for processing and identifying transient optical sources in real time [13–16]. For several of these flares, additional extensive studies were conducted at the KK astronomic observatory, Russian Academy of Sciences and other observatories, during which the physical parameters of the systems were obtained: the orbital period (and/or superhump periods), mass ratios, and a conclusion about their belonging to a certain subclass of CVs and evolutionary status was made [18–23].

In this paper, we present the results of photometric observations of the dwarf nova MASTER OT J044907.58+705812.7 [24] and other transients discovered with the telescopes of the Global MASTER Network.

2. BASIC PRINCIPLES OF OBSERVATIONS ON ROBOTIC TELESCOPES OF THE GLOBAL MASTER NETWORK AND AUTOMATIC SELECTION OF TRANSIENTS

The global network of robotic telescopes MASTER of Moscow State University that was created to search for, detect, and study astrophysical sources of high energies such as gamma-ray bursts [25–30], gravitational-wave bursts [31–34], sources of high and ultrahigh energy neutrinos [36, 35], fast radio bursts FRB [15], and others (including non-stationary processes in binary systems) conducts observations every night in alert and inspection modes automatically according to GCN target designations, as well as regular sky surveys during the remaining time [17]. Identical receiving equipment on all MASTER network telescopes allows automatic monitoring of alert messages 24 h a day and prompt observations on various telescopes in the network, ensuring the receipt of a continuous light curve in one photometric system and its analysis [17, 37]. A unique database of images of the northern (since 2002) and southern (since 2012) sky makes it possible to classify promptly objects from the archive of all MASTER network images according to the requested coordinates (target designation).

To detect automatically a new/variable source and confirm the flash/anti-flare registration, a minimum of two frames with the source per night with an offset between their centers is required to exclude hot pixels and cosmic particles from the list of transient candidates. Long data series over the night (for example, in the case of alert observations of gamma-ray bursts, monitoring of V404 Cyg, blazar TXS 0506+056 and others make it possible to classify immediately many objects discovered at this time by type. As a result, every night, in addition to the main tasks, optical variable sources of various types are detected: flares of blazars and quasars [38–43], supernovae of various types [44], exotic bright red novae [45], CPs, including classical novae [46–48], polars [49], dwarf novae [18–22, 50]; flares of red dwarfs [51], R CrB-type stars [52], systems of type ϵ Aur [53], as well as asteroids and comets [17, 54].

3. DWARF NOVA FLARES

This type of transients accounts for more than half of the objects registered by MASTER and is of considerable interest for subsequent, more detailed studies. Below are some examples of such discoveries.

Dwarf Nova[1] MASTER OT J195416.74+494421.1 with amplitude greater than 5.3^m, found by Kislovodsk MASTER in March 2019 (see Fig. 1). The system's magnitude at the time of discovery was 16.7^m. The image obtained with the limit of 19.3^m is used as a reference in 2019 (MASTER-Kislovodsk), the closest observation without registration of the object with a limit of 18.3^m that was received the day before discovery in Crimea (MASTER-Tavrida, March 21, 2019 01:31:59 UT). In the VIZIER database, within a radius of 5″, only the source from the Pan-STARRS catalog was present ($r_{\rm mag} = 21.6^m$), which produces a flash amplitude of more than 5^m.

Flare of a dwarf nova of the WZ Sge type MASTER OT J150719.46–283114.9 (AT2020bre) with amplitude greater than 7.2^m was discovered by the MASTER-IAC telescope [55] on February 1, 2020 03:50:00

[1] https://www.aavso.org/vsx/index.php?view=detail.top&oid=686856

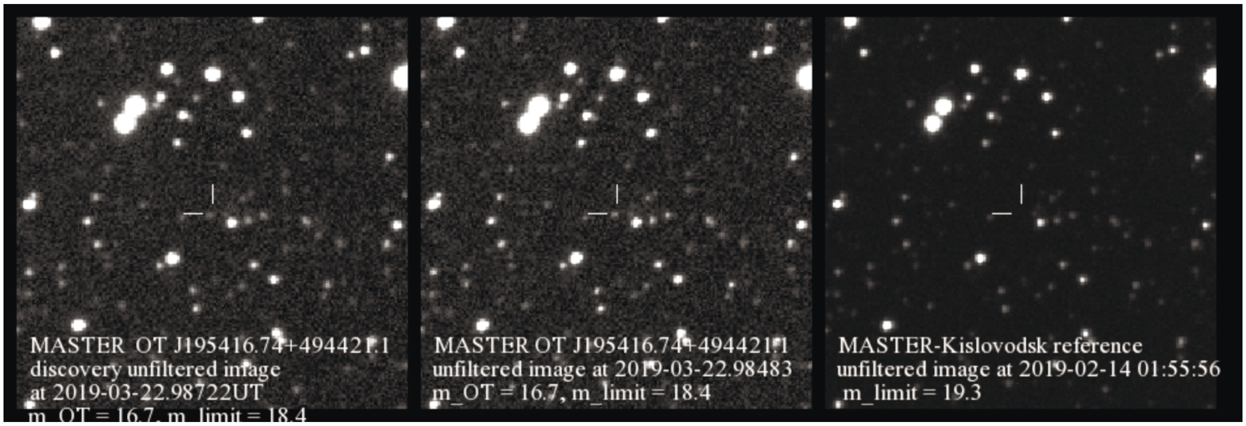

Fig. 1. MASTER OT J195416.74+494421.1 at the time of detection 2019.03.22.98483 UT and for comparison (on the right)—an archived image obtained 2019.02.14 01:55:56 UT with a limit of 19.3^m.

Fig. 2. MASTER OT J150719.46-283114.9 at the time of detection. On the right is the reference image obtained on 2019.06.09.89366 UT with a limit of $m_{\rm lim} = 18.5^m$.

UT (Fig. 2). The object is visible in four images with a magnitude of 14.8^m (60-s exposure, limit on each frame is 18.7^m, the start time of the exposures is February 1, 2020 (03:50:00, 04:02:00) UT and February 2, 2020 (03:56:48, 04:08:42) UT. The used reference image is for 2019. According to the MASTER archive since 2010, Palomar surveys, and VIZIER and AAVSO databases, no earlier flares have been registered.

Nova/Dwarf Nova Outburst MASTER OT J185835.32–354042.2 was discovered on April 12, 2018 (Fig. 3) with a magnitude of 16.7^m on the MASTER-SAAO telescope [56].

In previous MASTER images of this part of the sky, as well as in the VIZIER and AAVSO databases, no flares were detected. The object is visible on April 12 and 13, 2018 with the same brightness, which excludes the classification of the optical source as a gamma-ray burst, an orphan burst [28], or a red dwarf outburst, and imposes a constraint on the phase of the explosion: not the rising part of the light curve, but the maximum or post-maximum. The absence of a galaxy rules out a supernova of any type and Kilonovuyu (whose parent galaxy is always visible). White color ($m_V = 16.8^m$, $m_I = 16.9^m$, April 13, 2018 (22:33:38–22:49:27) UT, three exposures in each image with a duration of 180 s) and the absence in other images for nine years (the last image before the outburst on September 17, 2017, the first image after the active phase on September 3, 2018) on MASTER excludes the remaining options, except for Nova or dwarf nova, under which the object is currently recorded in AAVSO.

Dwarf Nova Outburst MASTER OT J174714.38+150048.1 in 2024 was discovered on September 5, 2024 during a regular survey in Crimea (MASTER-Tavrida, seven images that night). The object's magnitude in its current active state is 17.1^m

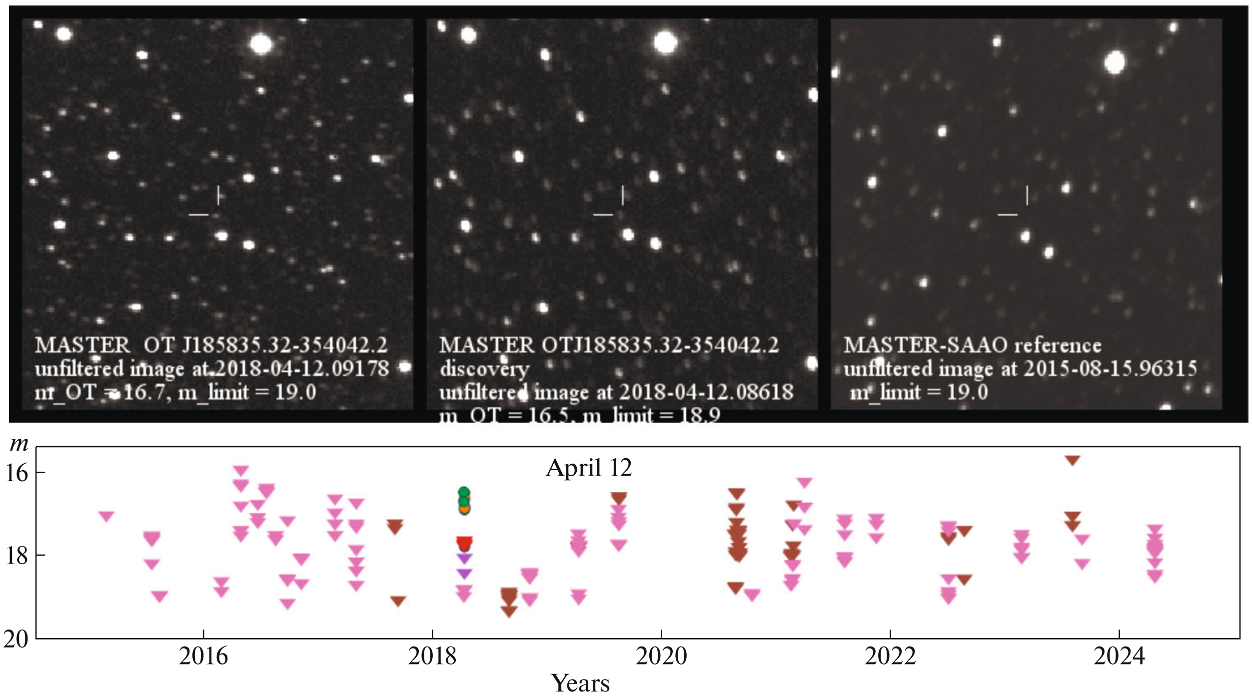

Fig. 3. Image of MASTER OT J185835.32–354042.2 at the moment the flare was detected and one of the reference images (top panel, right). The bottom panel shows the limits on images from 2015 to 2024 obtained in Argentina and South Africa (MASTER-OAFA, MASTER-SAAO).

($m_{\text{lim}} = 19.4^m$). Previous outbreaks, including 2020njy (17.4^m), are presented on the light curve (Fig. 4)

Outburst of a dwarf nova of the WZ Sge type MASTER OT J065054.42+593625.5 [57] was discovered on October 4, 2024 at 16:07:00 UT by the MASTER-Tavrida telescope.[2] In the VIZIER database, at these coordinates, there is an object from the GSC2.3.2 catalogues ($j_{\text{mag}} = 21.6^m$, in the red filter weaker than the limit), Pan-STARRs (close to the transmission of the MASTER matrices $r_{\text{mag}} = 21.4^m$, there are no objects brighter than 20.5^m in the MASTER database, which together produces a flash amplitude of more than eight magnitudes.

The object was also discovered[3] by one of the GOTO telescopes [58] and was observed with various instruments. The X-ray flux was measured by Einstein Probe detectors [59] on October 6 ($F = 8.1^{+1.9}_{-1.4} \times 10^{-14}$ erg/s/cm^2 in the range of 0.5–10 keV) and on October 11 at Swift-XRT [60] ($F = (8.9 \pm 3.7) \times 10^{-14}$ erg/s/cm^2, same range). The spectrum of the dwarf nova WZ Sge was obtained on October 8 (NOT/ALFOSC, in the range of 350–950 nm) and LT/SPRAT, 400–800 nm, confirming the Galactic affiliation of the object (Fig. 5).

[2] https://www.wis-tns.org/object/2024xhn

[3] https://www.astronomerstelegram.org/?read=16842

4. DETECTION AND OBSERVATIONS OF MASTER OT J044907.58+705812.7 FLARE

Object MASTER OT J044907.58+705812.7 (AT2024aaf) [24] was first discovered by the MASTER-Tunka telescope during a regular survey of the northern sky on January 14, 2024 with a magnitude of 16.6^m. According to the MASTER archive data from April 11, 2005 (Fig. 6), VIZIER (DSS, Pan-STARRs), no brightening of the object was registered. ATLAS [61] reported[4] that in his frames obtained on January 4, 2024, an object was detected, but it was incorrectly classified as a supernova, and no telegram about the discovery was published. An analysis of data from the TESS space observatory [62] for 2019–2023 using the Lightkurve package [63] showed that the object was below the sensitivity limit of the device and did not show activity until the outburst in 2024. CRTS [64] did not conduct a survey at these latitudes.

Following our publication in TNS [24], ASASSN found the source in their images and added it to AAVSO [65], subsequently photometry of the January outburst (from 2024.01.04.390 UT) in ATLAS as a potential supernova appeared, and on February 29, GAIA published a report on observations for January 7.

[4] https://www.flickr.com/photos/snimages/53502503728/

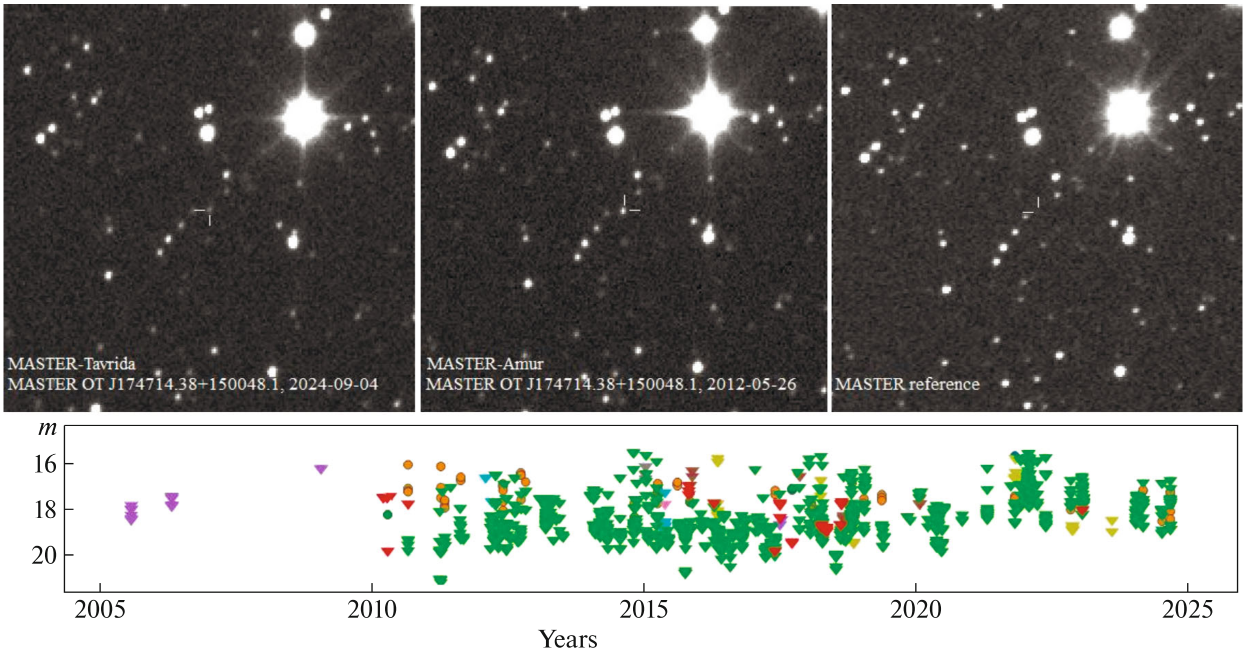

Fig. 4. Images of MASTER OT J174714.38+150048.1 during outbursts in 2024 and 2012 and a reference image (top, right). Below are the light curve and limits in white light, with different colors showing the values obtained at the MASTER-Amur, MASTER-Tunka, MASTER-Kislovodsk, MASTER-Tavrida, MASTER-YuAR and MASTER-IAC stations.

4.1. First Gloss Estimates

Since the discovery of object MASTER OT J044907.58+705812.7, its monitoring observations have been carried out using the MASTER-Tunka and MASTER-Kislovodsk telescopes in the *BVRI* bands, as well as in wide band *W* (without filter) (Table 1). The observations were carried out in the converged tube mode, so MASTER obtains synchronous estimates of the star's brightness in two photometric bands.

Photometry was performed using the AstroimageJ specialized program [66]. This program is designed specifically for precision aperture photometry and allows taking into account the features of the telescope's CCD matrix, background heterogeneity across the frame, and atmospheric absorption. The program makes it possible to study the behavior of comparison stars and discard those that turn out to be variable. In the photometry of MASTER OT J044907.58+705812.7, field stars were used as references selected so that their stellar magnitudes and color indices were close to those of the object under study. For frames obtained without a filter, the standard stellar magnitudes were taken as *G*-values from Gaia DR3 [67]. For *BVRI* photometry, the values of references obtained based on low-resolution spectroscopy using the synthetic photometry method and published in [67] were used. As a result, multicolor photometry of the object in stripes *BVRI* and without a filter for a period of more than 50 days of monitoring was obtained. A total of 280 gloss ratings were obtained. The light curve to a high degree (up to 0.1^m)

Table 1. MASTER OT J044907.58+705812.7 observation log from January 14, 2024 (JD 2460000+)

Observatory	HJD, beginning	HJD, end	Filter	*N*	σ
MASTER-Kislovodsk	324.25869	342.35310	*B*	24	0.17
MASTER-Kislovodsk	324.25870	345.17925	*V*	28	0.19
MASTER-Kislovodsk	324.23998	340.16455	*R*	29	0.19
MASTER-Kislovodsk	324.23998	345.17228	*I*	34	0.26
MASTER-Kislovodsk	324.16100	328.24549	*W*	18	0.16
MASTER-Tunka	323.97810	324.45759	*W*	147	0.02

σ is the average accuracy of observations in stellar magnitudes.

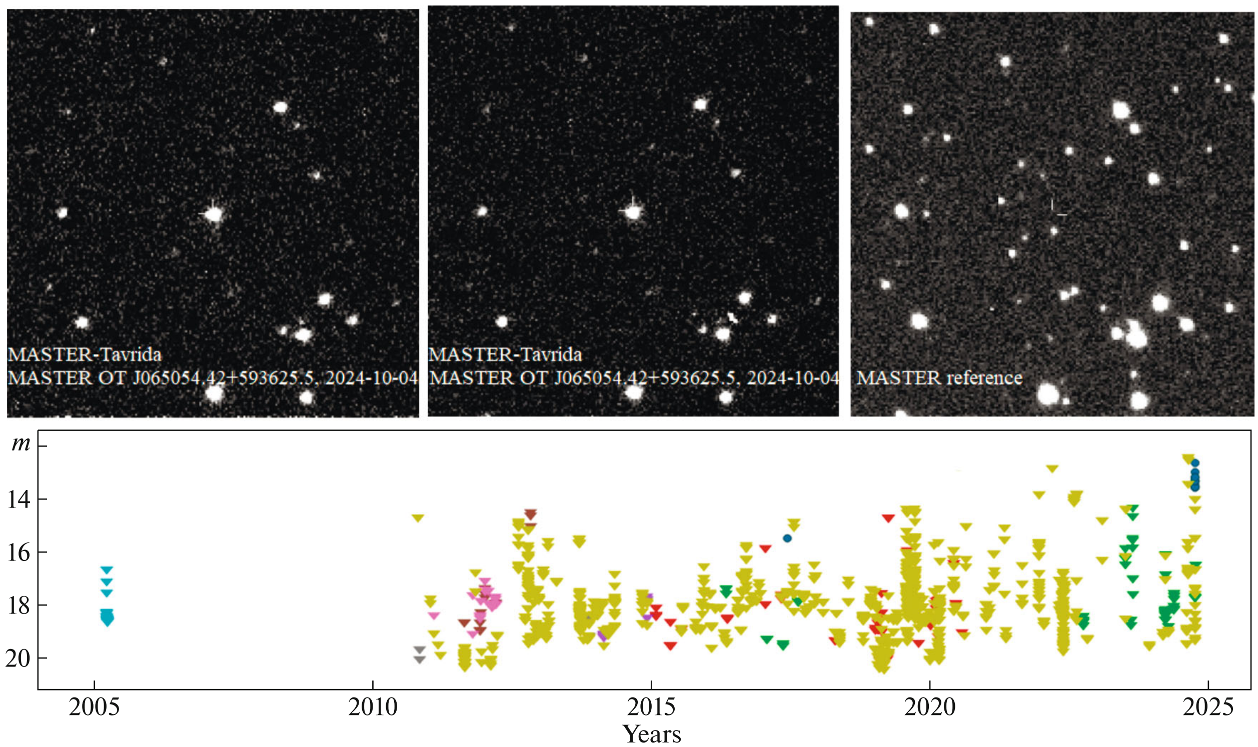

Fig. 5. MASTER OT J065054.42+593625.5 flare and comparison frame with limit 20^m (top, right). Below are the light curve and limits of the object based on images from the MASTER archive since 2006.

is consistent with observations at CrAO (the general light curve is shown in Fig. 7).

4.2. Observations of MASTER OT J044907.58+705812.7 in CrAO

Three days after the discovery of the object, multicolor observations were carried out in the Johnson-Cousins photometric system bands *UBVRcIc* or without using light filters at the Crimean Astrophysical Observatory (CrAO) using the 1.25-m AZT-11 telescope with the CCD Greateyes ELSE-i 2k × 2k BI MID. Observations were carried out over 14 nights from January 17 to March 14, on the last night—using the 2.6-m ZTSh telescope also without light filters (see the observation log in Table 2) with CCD Greateyes ELSE-i 1k ×1k BI MID. We used the MAXIM DL package for aperture photometry after standard processing (accounting for bayesian, dark signal, and flat field). The brightness of the object was measured relative to three comparison stars: USNO B1.0 1609–0062095 ($B_2 = 17.49^m$, $R_2 = 16.21^m$, $I = 15.91^m$), 1609–0062067 ($B_2 = 16.97^m$, $R_2 = 16.09^m$, $I = 15.88^m$), and 1609–0062077 ($B_2 = 16.63^m$, $R_2 = 15.61^m$, $I = 15.28^m$). A total of 510 brightness estimates were obtained during the observation period.

4.3. Light Curve Analysis

Figure 7 shows the general long-term light curve in the most representative *R* band (or without a filter) based on observations from the CrAO and MASTER telescopes with the use of archival data from ZTF [68].

Around JD 2460340, a rebrightening and subsequent rapid fading was recorded at $\sim 2.5^m$ in two days in a strip close to *Rc*. The color indices indicate that the object is blue at the maximum of its light curve and gradually becomes redder as it fades. From the time of the first brightness estimate obtained by MASTER until the last estimate made at CrAO, the object has weakened by $\sim 3.5^m$ and achieved $R \sim 19.8^m$. The amplitude of the flash was 5.5^m (or 6^m if we take into account the single ZTF estimate), however, at the end of the observations the object had still evolved to its pre-flare level, reaching only 22^m, since it was not detected on Pan-STARRS with a threshold of 24^m. In this case, the amplitude of the flash must be 7.5^m–8^m.

During the fading stage, four rebrightenings with an amplitude of $\sim 2.5^m$ and playback frequency $\sim 4.8^d$ were recorded. Interestingly, a third of the 18 dwarf novae with repeated brightenings, including two objects discovered by MASTER (MASTER OT J085854.16–274030.7 [69] and MASTER OT

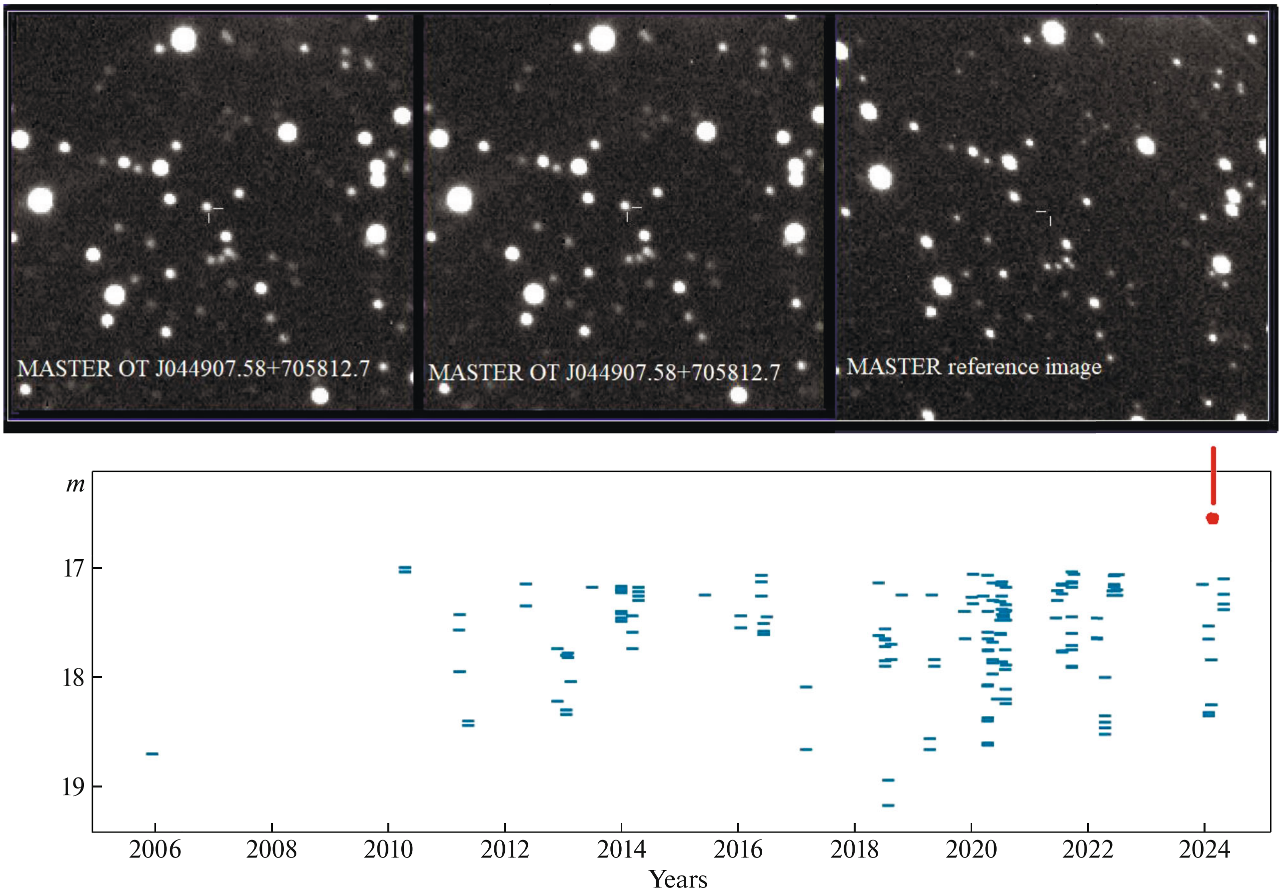

Fig. 6. Flash MASTER OT J044907.58+705812.7 and reference image in white light (top, right). Below are the limits on images from the MASTER archive for the period of 2006–2024, illustrating the rarity of such states in the system (the first registration of a flare in the history of observations).

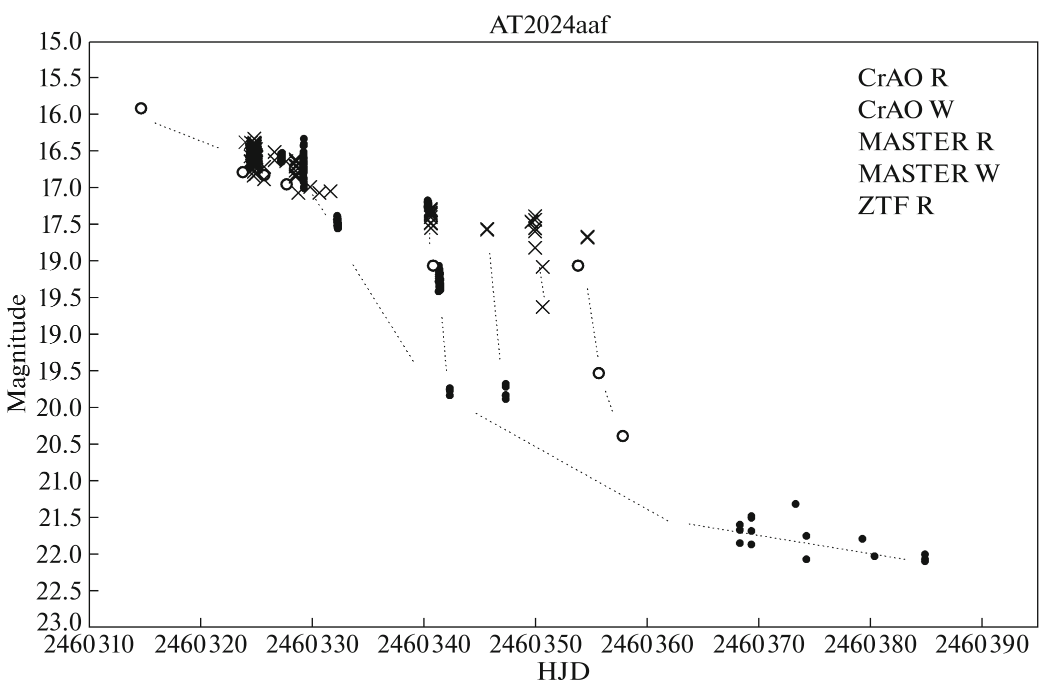

Fig. 7. Light curve of MASTER OT J044907.58+705812.7. The dots indicate data obtained in CrAO, the crosses indicate data obtained by MASTER, and the circles indicate archival data from ZTF.

Table 2. MASTER OT J044907.58+705812.7 observation log in CrAO (HJD 2460000+)

Date	HJD, beginning	HJD, end	Filter	N	σ
Jan. 17/18	327.18283	327.29779	U	20	0.04
	327.17831	327.29966	B	20	0.04
	327.17948	327.30083	V	20	0.07
	327.18030	327.30166	Rc	20	0.01
	327.18113	327.30248	Ic	20	0.08
Jan. 19/20	329.17650	329.24788	—	47	0.06
Jan. 22/23	332.19282	332.20526	B	3	0.07
	332.19400	332.20643	V	3	0.04
	332.19482	332.20726	Rc	3	0.02
	332.19565	332.20808	Ic	3	0.02
	332.21474	332.29878	—	104	0.02
Jan. 20/31	340.30053	340.31298	B	3	0.07
	340.29929	340.31275	V	3	0.04
	340.30503	340.31747	Rc	3	0.02
	340.30586	340.31829	Ic	3	0.02
	340.32214	340.41931	—	120	0.02
Jan. 31/01	340.30053	340.31298	B	3	0.07
	340.29929	340.31275	V	3	0.04
	340.30503	340.31747	Rc	3	0.02
	340.30586	340.31829	Ic	3	0.02
	340.32214	340.41931	—	77	0.02
Feb. 01/02	342.29447	342.30129	—	4	0.02
Feb. 06/07	347.30268	347.31151	—	5	0.07
Feb. 27/28	368.27953	368.28835	—	3	0.10
Feb. 28/29	369.29229	369.30111	—	5	0.10
March 3/4	373.25456		—	1	0.12
March 4/5	374.22732	374.23505	—	2	0.15
March 9/10	379.23228		—	1	0.15
March 10/11	380.32475		—	1	0.15
March 14/15	384.34894	384.34972	—	4	0.06

"—" means that the observations were made without a filter. σ is the average accuracy of observations in stellar magnitudes.

J211258.65+242145.4 [70]), for which the amplitudes of brightenings and the frequency of their occurrences were measured [71], have similar characteristics: the average amplitude of brightenings is 2.3^m and the average frequency is 4.8^d. Due to gaps in the observations of MASTER OT J044907.58 +705812, it cannot be said that there were no more repeated brightenings.

At the maximum of the outburst, the object showed blue color excesses close to zero that are characteristic of dwarf novae during the plateau of a superoutburst [72]: for JD 2460327, $B = 16.777(6)^m$, $R_c = 16.577(8)^m$, and $I_c = 16.669(8)^m$. Quasi-simultaneous photometry on this night in bands $UBVRcIc$ revealed synchronous brightness fluctuations in them with an amplitude of $\sim 0.1^m$ and characteristic time of $\sim 0.06^d$ (Fig. 8), which we identified as superhumps at the maximum of the dwarf nova superoutburst.

We have combined the data on B, V, R_c, and I_c into one array for a given night, bringing them to the average brightness level, and constructed a periodogram for them (Fig. 9, left) using the Stellingwerf method [73] implemented in the ISDA software pack-

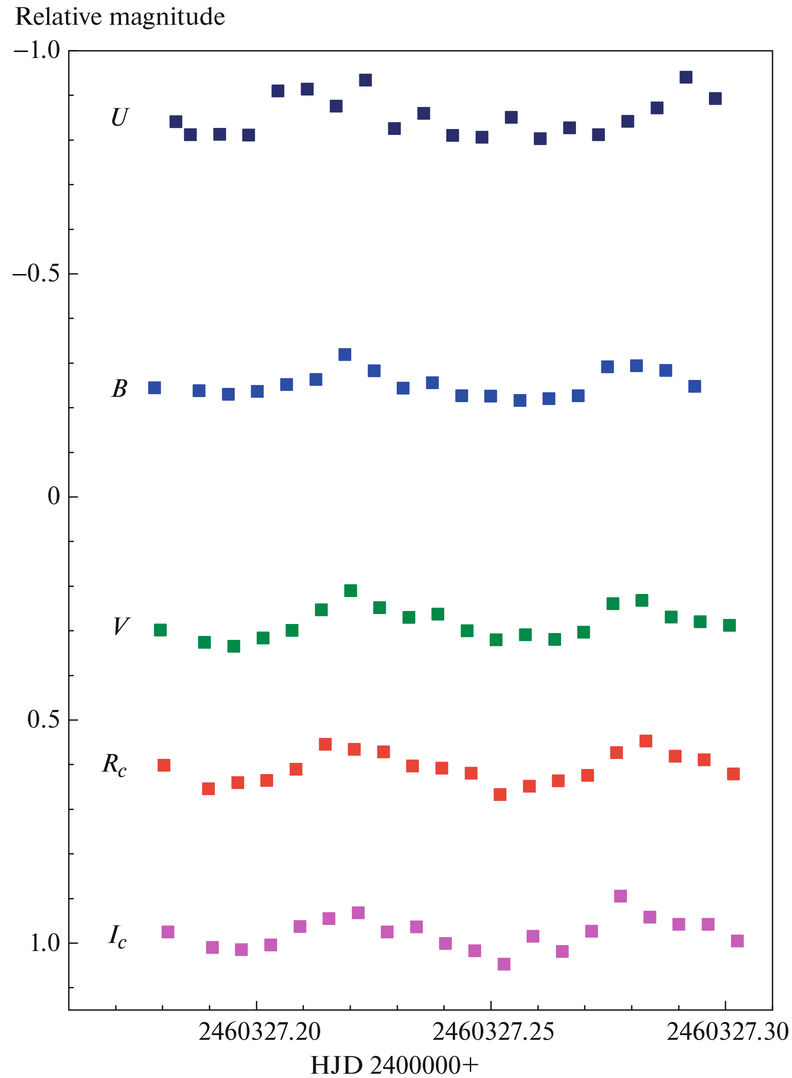

Fig. 8. Short-period light curves of MASTER OT J044907.58+705812.7 in different filters.

age [74], which indicated a period of $0.060(1)^d$. The convolution with this period is shown on the right in the figure. Unfortunately, the lack of sufficiently long observations on subsequent nights made it impossible to follow the evolution of the superhumps.

Large flash amplitude, blue color at maximum, $\sim 0.06^d$, fluctuations in brightness during the outburst, a long return to a quiet state, and the presence of at least four repeated brightenings give grounds to classify the object as a dwarf nova of the WZ Sge type with multiple brightenings [71]. Some dwarf novae of the WZ Sge type with repeated brightenings, according to Kato [71], may turn out to be exotic objects containing a secondary component: a brown dwarf. Very few such objects have been found at present, so their search and study is a very urgent task.

5. DISCUSSION AND CONCLUSIONS

Objects discovered and classified by MASTER during outbursts provide a unique opportunity to obtain photometry during the active phase and study rare objects [7, 75–77], including cataclysmic variables with large amplitudes or unusual light curve shapes. In this study, photometry was obtained for dwarf novae, which belong to the subclass of cataclysmic variables. We focused on detailed follow-up photometry of one of these objects, MASTER J044907.58+705812.7. This object was discovered by the MASTER-Tunka telescope [24] in a flare having a magnitude of 14.7^m and was identified as a WZ Sge-type dwarf nova by the following criteria.

An analysis of archival data from the MASTER surveys (2005, 2010–2024), ATLAS [61] (up to 20^m), Pan-STARR [78] (up to 24^m), and TESS [62] (19.6^m) showed that no previous outbursts were detected (not

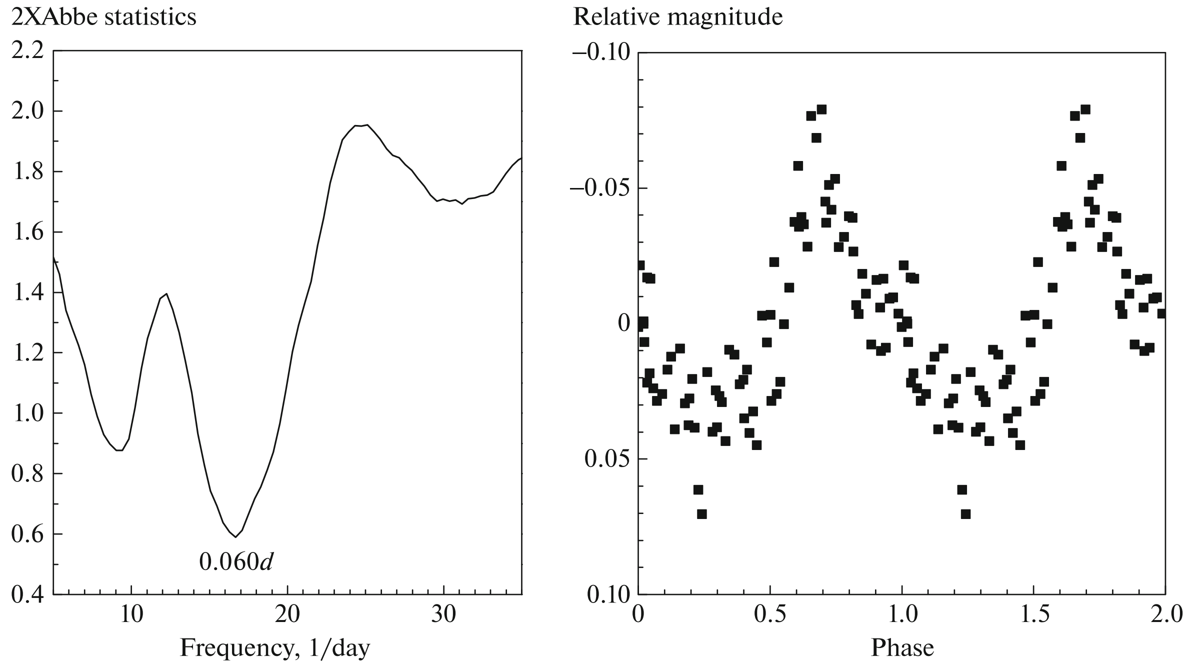

Fig. 9. Periodogram for MASTER OT J044907.58+705812 (left) and phase curve folded with period 0.060^d (on the right).

a Mira with an increase in brightness, not a variable star of other types).

The joint monitoring of MASTER OT J044907.58+705812.7 conducted at the CrAO telescopes and at the MASTER-Kislovodsk, MASTER-Tunka telescopes revealed a large amplitude of the flare (more 7^m) and a long-term (at least 50 days) return to a calm state. This light curve is typical for dwarf novae of the WZ Sge type and excludes the possibility of another interpretation (not a gamma-ray burst, not a red dwarf, not a supernova, not an eclipsing type ϵ Aur, and non-moving object (asteroid, comet, near-Earth man-made objects). The blue color of the object and the presence of superhumps during the outburst confirm that the object belongs to dwarf novae, and the presence of at least four repeated brightenings during the decline of the outburst's brightness makes it possible to classify MASTER OT J044907.58+705812.7 as a WZ Sge-type dwarf nova with multiple brightenings, which may turn out to be an exotic object—containing a secondary component—a brown dwarf.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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