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LW Cassiopeiae and Its Environment

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Recent multicolor photometry of N. Kurochkin's nova or novalike variable star LW Cas has been obtained using the SAO 1-m Zeiss reflector. The amplitude of the outburst in 1952 was 5^{m} in the B band. In 2008, LW Cas consists of a central stellar object of 20^{m} B surrounded by a halo of the same brightness and a $7''$ comet-like tail directed to the east. The star is associated with a young star-forming region and seen through a dark cloudy nebulosity. There is evidence of bright light echo seen two years after the outburst.

1 INTRODUCTION

LW Cas (SVS 1144) was discovered by Kurochkin (1953) and classified as a novalike star or slow nova. It was first detected on 1951 September 27 (JD 2433917) at the level of $16\overset{\mathrm{m}}{.}55$ pg and reached its maximum at $15\overset{\mathrm{m}}{.}4$ pg on 1952 January 25 (JD 2434037) after continuous brightening. After the maximum, a very slow decay with the rate of $0\overset{\mathrm{m}}{.}04$ in 100 days and with rare dips was observed. In a more detailed paper, Kurochkin (1959) published a ten-year light curve, which showed that the variable star was seen for 5 years above the limit of photographic plates estimated as 17^{m}. Examining the Palomar Observatory Sky Survey (POSS) images, he noted that the star was located in the region rich for bright and dark details of the nebula IC 1848-S6, in the middle of a small sine-shaped filament of dark matter. The filament is seen wedged in the main volume of the nebula. Kurochkin described also a light halo around the star in the POSS negative that might be a concentration of dark matter to the star's image. He noted that the image of the star was elongated from east to west and had an oval shape, in variance to other surrounding stars. This POSS image was taken in January, 1954 during the outburst. He supposed that the elongation might be due to binarity of the star or to a luminous nebular shell.

Cohen (1980) described LW Cas (No. 11 in the list) as a highly absorbed ($A_V = 5\overset{\mathrm{m}}{.}5 \pm 0\overset{\mathrm{m}}{.}1$) A0III star having $V = 17\overset{\mathrm{m}}{.}9$. Based on unpublished infrared observations by Herbig, Cohen noted that the star was associated with a parabolic nebulosity at whose tip there was an infrared source. High-frequency radio continuum emission was also observed from the star. LW Cas is the infrared star IRAS 02534+6029 or 2MASS 025721.6+6041198 ($J = 12\overset{\mathrm{m}}{.}49 \pm 0\overset{\mathrm{m}}{.}02$; $H = 11\overset{\mathrm{m}}{.}09 \pm 0\overset{\mathrm{m}}{.}03$; $K = 10\overset{\mathrm{m}}{.}03 \pm 0\overset{\mathrm{m}}{.}03$). Cohen also gave the following IR indices for LW Cas: $[1.6\mu] = 10\overset{\mathrm{m}}{.}31 \pm 0\overset{\mathrm{m}}{.}07$; $[2.3\mu] = 9\overset{\mathrm{m}}{.}11 \pm 0\overset{\mathrm{m}}{.}02$; $[3.5\mu] = 7\overset{\mathrm{m}}{.}95 \pm 0\overset{\mathrm{m}}{.}05$; $[4.9\mu] = 6\overset{\mathrm{m}}{.}58 \pm 0\overset{\mathrm{m}}{.}02$.

Wenzel and Fuhrmann (1983) took a poorly exposed spectrogram of LW Cas with the Russian 6-m telescope. In this spectrum, LW Cas showed neither emission nor absorption lines. Its nebular appendix to the east was described as a low-excitation nebula. They discussed this star as "an FU Ori type object after a recurrent outburst".

Moffat (1972) estimated the photometric distance to IC 1848 complex as 2.29 kpc, and Georgelin and Georgelin (1970) estimated its spectroscopic distance as 2.30 kpc.

LW Cas entered the field of our interests as a possible red nova candidate with a remnant bright in the infrared range. It is reasonable to study it having in mind that the best-studied red nova, V838 Mon, is a young object, also associated with gas and dust. In that case, circumstellar matter manifested itself through the light echo of the outburst. The amplitude of the 1951 outburst of LW Cas is still unknown, and we performed special photometry to study the star in the quiescent state and to revise Kurochkin's eye estimates during the outburst.

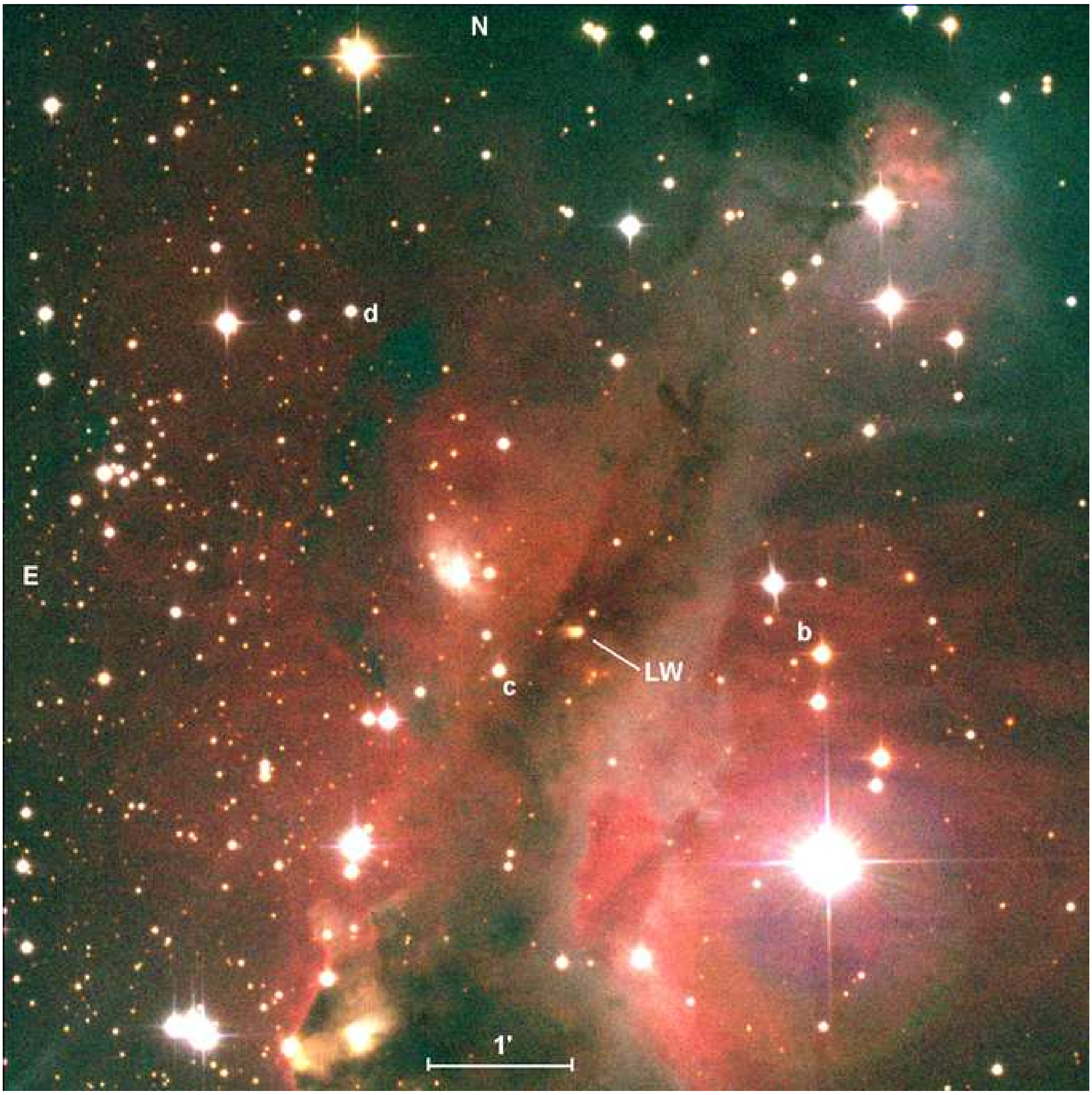

Figure 1. A color picture of LW Cas and its surroundings. Stars b, c, and d are comparison stars used by N.E. Kurochkin for eye estimates. This frame was taken with the SAO 1-m Zeiss telescope.

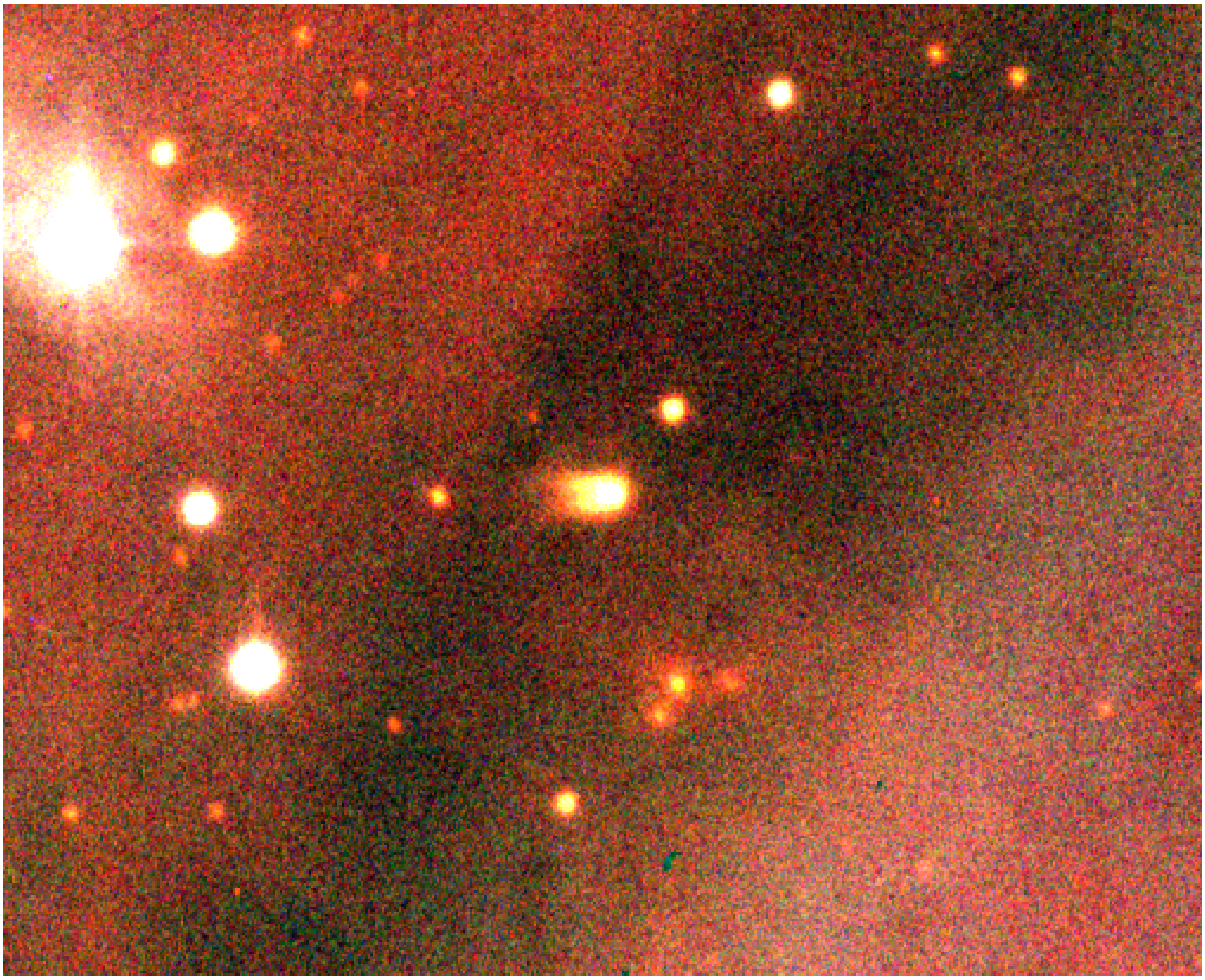

Figure 2. LW Cas (in the center) and its close neighborhood. A fragment of the frame taken with the SAO 1-m Zeiss telescope.

2 OBSERVATIONS

Our BVR_CI_C photometry was performed using the 1-meter Zeiss reflector of the Special Astrophysical Observatory with an EEV 42-40 CCD on 2008 January 2, 12, 13 and February 3. In these frames, the image scale is $0\farcs22$ per pixel with binning 1 and $0\farcs44$ per pixel with binning 2. The best seing, FWHM $\approx 1\farcs0$, was on January 13. On that night, we accumulated deep frames with the exposures of 600 s in the V and R filters and of 900 s in the B filter to get high-resolution color images of LW Cas and its surroundings. The color image of the IC 1888-S6 region is shown in Fig. 1. This image was cleaned for traces of cosmic particles, hot pixels, and chip defects. The original uncleaned 25-Mb color FITS-format frame and its cleaned bitmap image can be downloaded from Vitaly Goranskij's web site (http://jet.sao.ru/∼goray/lwcas/lw1color.fts and .../lw1color1.bmp).

Figure 1 demonstrates IC 1888-S6 as a complex structure including star clusters, gas and dust nebulae. Some bright and faint stars are embedded in the gas and dust matter. The star light is absorbed by dust as well as reflected by dust clouds. The reflected light may be blue as at the NW edge of nebula, yellow as at the SE edge, or red as in the center depending on the color of the star. The brightest and hottest star in the right bottom of the frame ionizes hydrogen in its far vicinity. LW Cas is blocked by the belt of dark matter going from the SE to the NW edge of nebulosity and having cloudy structure. In 17″ to SW of LW Cas, three stars surrounded by common bright nebulosity are also blocked by the same dark belt. Some dark details of this belt have a strange V-shape.

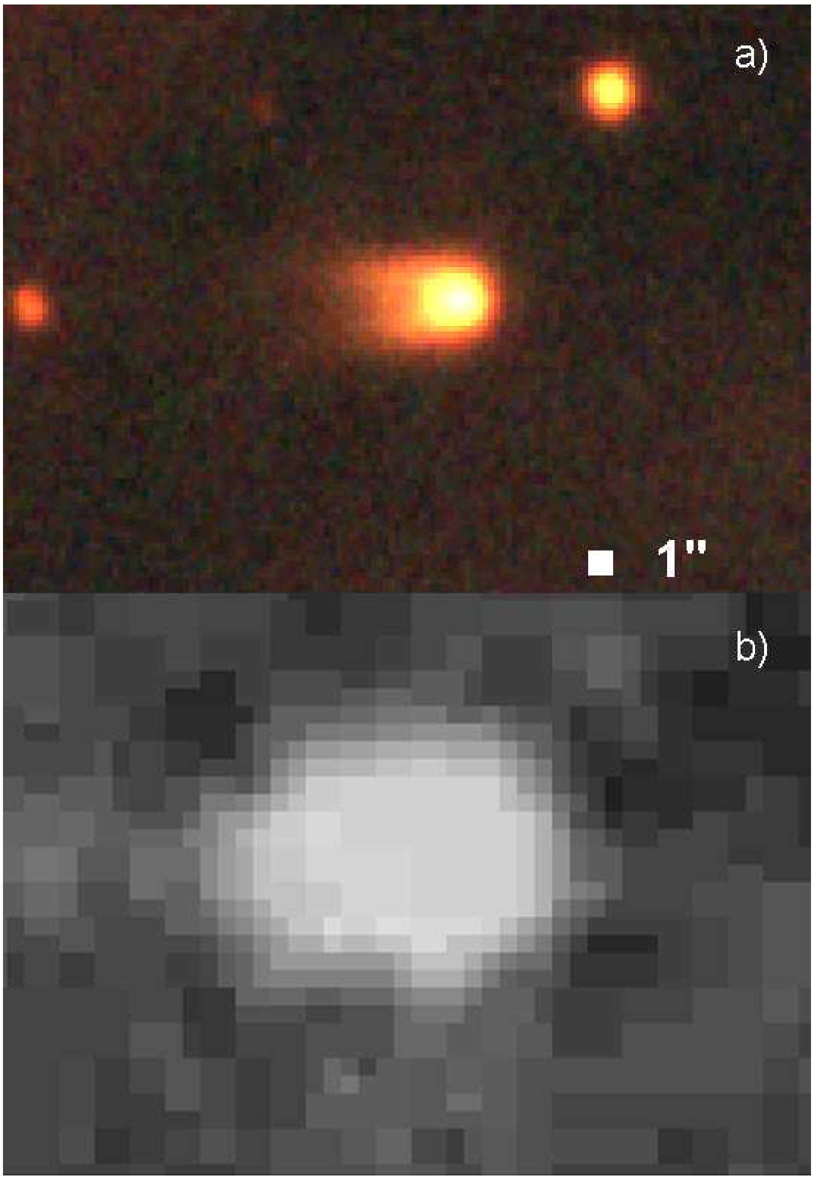

Figure 3. The cometary nebula of LW Cas: (a) January, 2008; (b) January, 1954 (POSS-E). Both images are reduced to the same scale. The POSS red image is elongated due to light echo.

The enlarged fragment of the dark belt is shown in Fig. 2. In this Figure, we do not see the dark halo around the star noted by Kurochkin (1959) as a light one on the POSS negative, nothing can be treated here as a dark globula. LW Cas itself has a comet-like tail directed to the east that can be traced for 7″ in our best frames (Fig. 3a). High-contrast images show that the star with a tail is located in a faint ellipsoidal nebulosity, 7″ × 10″ in size. In Fig. 3a, the tail of LW Cas looks like an empty conic or paraboloidal structure. With the given resolution, one can suggest a different interpretation of this image as a star located at the tip of a dark and dense, elongated conic structure resembling a pillar or an 'elephant trunk' (which are met in other star-forming regions), and the star illuminates the nearby sides of this structure.

On two nights with stable air transparency, we made absolute measurements of two Kurochkin's standard stars in this region, b and c. These data are given in Table 1. The JHK data in this Table are taken from 2MASS.

Table 1. BVR_CI_C magnitudes of two Kurochkin's comparison stars

Star	B	V	R_C	I_C	J	H	K
b	$15^{\mathrm{m}}.46$	$14^{\mathrm{m}}.20$	$13^{\mathrm{m}}.56$	$12^{\mathrm{m}}.72$	$11^{\mathrm{m}}.35$	$10^{\mathrm{m}}.68$	$10^{\mathrm{m}}.51$
c	16.78	15.84	15.30	14.73	13.59	13.17	13.04

LW Cas itself was measured using an aperture of $5''.2$ diameter centered on the star in the CCD frames. The results of our BVR_CI_C photometry are presented in Table 2.

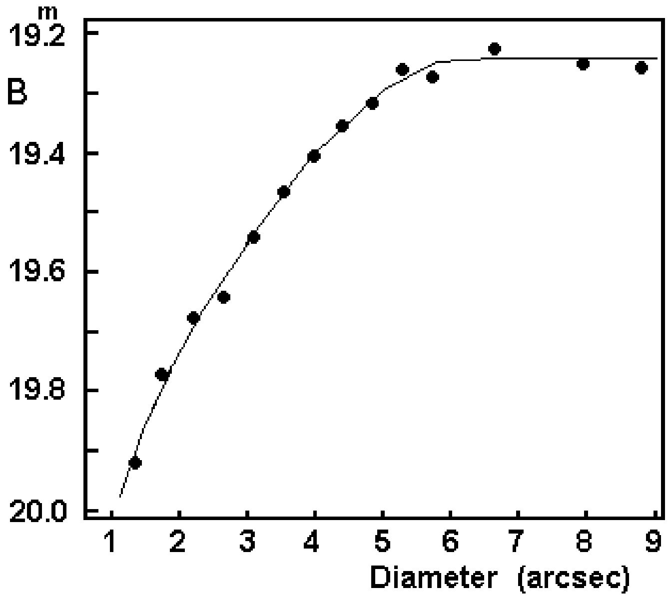

Figure 4. The dependence of the brightness of LW Cas on the aperture diameter. This dependence reveals the nonstellar structure of the central object.

Table 2. BVR_CI_C observations of LW Cas with the $5''.2$ aperture

JD 2454...	B	V	R_C	I_C
468.300	$19^{\mathrm{m}}.26$	$17^{\mathrm{m}}.75$	$16^{\mathrm{m}}.56$	$15^{\mathrm{m}}.24$
478.219	19.27	17.73	16.57	15.26
479.297	19.29	17.70	16.57	–
479.312	19.25	17.72	16.57	–
479.321	19.25	17.71	16.57	–
500.244	19.17	17.67	16.51	15.28

Additionally, we remeasured all Kurochkin's standard stars to correct his photographic magnitude scale used for eye estimates. The corrected magnitude in maximum transferred to the photometric B scale is $15^{\mathrm{m}}.0$. The mean magnitude in minimum given in Table 2, $B = 19^{\mathrm{m}}.25 \pm 0^{\mathrm{m}}.04$, was measured using a $5''.2$ aperture, it is apparently distorted by the surrounding nebula. We tried to estimate the contribution of the star and the nebula to the photometric magnitudes using measurements with different apertures, in the range between $1''.3$ and $8''.8$. The B-band CCD frame taken on 2008 January 13 with the resolution of FWHM = 1″.0 was used. Figure 4 shows the relation between the measured magnitude of LW Cas and the diameter of the aperture. This Figure reveals that the central object does not have a stellar structure but possesses a halo that contributes approximately a half of its light. The extrapolated magnitude of the central star in the 1″ diaphragm is $B = 20^{\rm m}.0 \pm 0^{\rm m}.1$. The halo and tail contribute the same amount of light as the stellar object. Thus, the amplitude of the central star's outburst was about $5^{\rm m}.0$ or somewhat larger in the B band. The star became 100 times brighter in the outburst compared to the current quiescence.

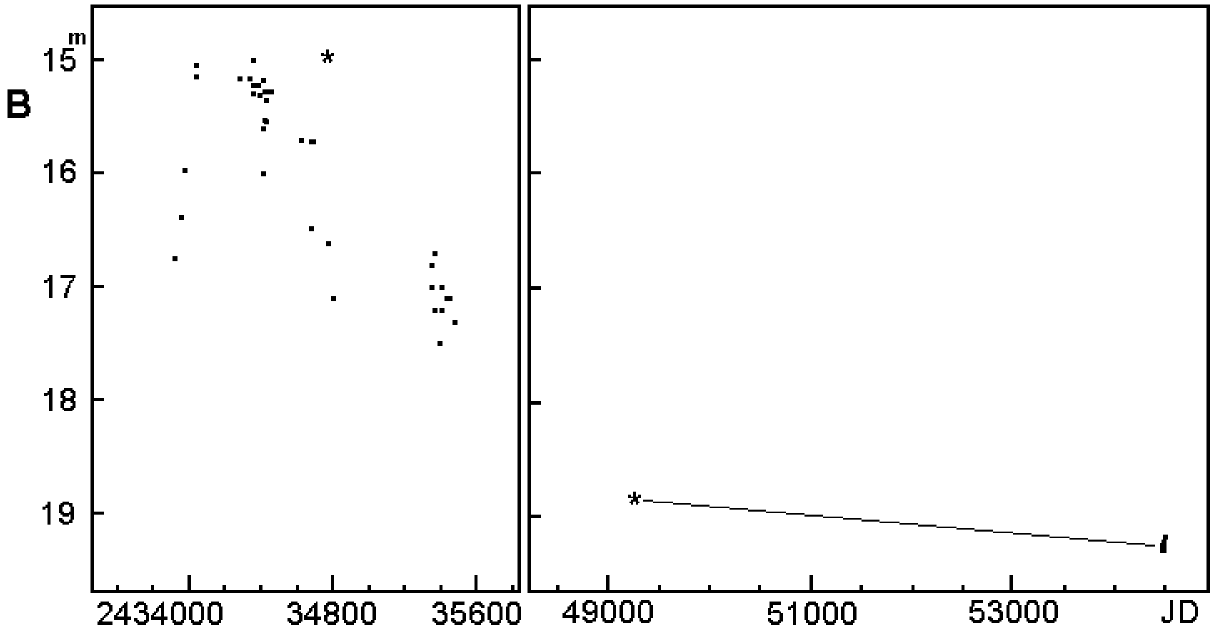

Figure 5. The light curves of LW Cas during the outburst and in quiescence.

Using remeasured standard stars, we have determined accurate magnitudes of LW Cas in the two POSS digitized images. The light curve of LW Cas in Fig. 5 consists of two fragments, Kurochkin's eye estimates (left) and contemporary data (right). Asterisks in both panels denote POSS blue plate measurements. The first POSS observation taken on the night of JD 2434770 is really brighter by $1^{\rm m}$ than the estimate by Kurochkin on the previous night, as noted by Kurochkin (1959). POSS blue and red images of LW Cas are evidently elongated from the east to the west (the POSS red image is shown in Fig. 3b). This fact is surprising because the nebulosity around the star contributes the amount of light of only $20^{\rm m}$ and the $16^{\rm m}$ central star's image being 40 times brighter should cover it. We suppose that this was the light echo that spread along the tail of LW Cas, and it was responsible for the elongated shape of the image. On the second year of the outburst, the central star declined by one magnitude relative to its maximum brightness, and the echo was still bright and comparable to the star, which determined such a uniformly elongated shape of the image. The light echo can be expected in such a dense dusty environment, for such a strong outburst.

The spectral energy distribution (SED) including the optical photometry and appended with published infrared data is shown in Fig. 6. The red points are the results of observations not corrected for interstellar reddening, and the black points are those corrected for interstellar reddening corresponding to $A_V = 5^{\rm m}.5$ (Cohen 1980). Small points in Fig. 6 represent the optical energy distribution of the A0 star Vega published by Glushneva et

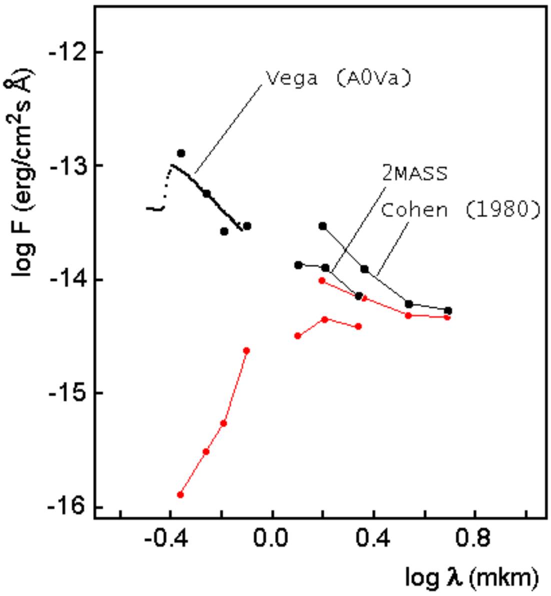

Figure 6. The spectral energy distributions of LW Cas in the optical and infrared bands. Interstellar reddening was taken into account for the black points, no correction was introduced for the red points. The SED of the A0 star Vega is plotted as small points. The SED of Vega is arbitrarily displaced along the flux axis.

al. (1992). The SED of Vega (A0Va) fits well the distribution of LW Cas. No strong IR excess typical of red-novae remnants is visible. However, some weak IR excess was probably present in 1970s, when the observations by Cohen were made. Cohen's points are located evidently higher than the 2MASS poins.

3 DISCUSSION AND CONCLUSIONS

The nature of Kurochkin's nova or novalike variable LW Cas remains enigmatic. Unfortunately, no deep images of LW Cas taken before its outburst in September 1951 have been reported so far, and we have no information on its pre-outburst brightness. The star is surrounded by a nebular envelope, and taking its contribution into account reveals that the central star brightness decayed at least by 5^{m}, or by a factor of 100, in the B band during 56 years after the brightness maximum. This excludes the classification of LW Cas as an FU Ori star. FU Ori itself had the B-band amplitude of 7^{m} in its outburst in 1934, but showed a decay only by 1^{m} during the following 46 years (GCVS). Its spectrum was F2I–IIpeaq in the state of constancy.

V1057 Cyg was a T Tau star varying between $15\overset{m}{.}5$ and $16\overset{m}{.}5$ before its novalike outburst, and had an outburst to $10\overset{m}{.}3$ in 1960–1970. In 2008, it varied at the brightness level of about $13\overset{m}{.}1$, so that the decay was about 3^{m} for 48 years. Its spectrum was B2 at maximum light and G2–G5Ib after the maximum. Some researchers classify V1057 Cyg as an FU Ori star. However, this event demonstrates that young T Tau stars can experience such strong outbursts as that of LW Cas. Another FU Ori star, V1515 Cyg, had the amplitude of 4^{m} and the spectrum G0–G5eaqIb. GCVS describes FU Ori stars as "characterized by gradual increases in brightness by about 6 mag in several months, followed by either almost complete constancy at maximum that is sustained for long periods of time or slow decline by 1–2 mag. Spectral types at maximum are in the range

Ae(alpha) – Gpe(alpha)". There is no positive information that FU Ori stars can undergo recurrent outbursts, as speculated by Wenzel and Fuhrmann (1983).

LW Cas has declined by 5^{m} by the present time, and special monitoring is needed to check if it has reached constancy. The range of variability in the "constancy" is another goal of future monitoring. Photometric observations can answer the question on its single or binary nature. A good spectrum in the quiescent state is urgently needed.

Our photometry shows that LW Cas stays a hot star after its outburst, and no cool remnant is seen in the energy distribution, no emission of heated dust in the infrared range. Thus, it has nothing in common with red novae. The duration of outburst is much larger than those of the red novae. Probably, the LW Cas phenomenon is an outburst of a young T Tau star like V1057 Cyg.

The analysis of POSS plates reveals the presence of a light echo after the outburst. However, the light echo is typical of many types of stellar outbursts that happen in dense dusty environment.

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