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LS And: WZ Sge-type outburst first time since the 1971 discovery

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Abstract

LS And was a transient discovered in 1971 in the M 31 region and it has been argued whether it could be an intergalactic nova or a dwarf nova. Using the Zwicky Transient Facility (ZTF) data, I found that the object underwent the second known outburst in 2022 April. The behavior was that of a WZ Sge-type dwarf nova with a long fading tail and the light curves of the 1971 and 2022 outbursts matched very well. The light curves suggest that LS And is a typical WZ Sge-type dwarf nova near (but before reaching) the period minimum of cataclysmic variables. The true observed peak of the 1971 outburst was likely 12.2 mag. The outburst parameters were similar to those of other WZ Sge-type dwarf novae. The fading tail lasts more than a year and the object is still currently on this tail. There was a hint of 0.5-mag temporary brightening on the fading tail and the object appears still active after the outburst.

LS And was discovered by van den Bergh et al. (1973) in the region of M 31 (named "m" in their paper). van den Bergh et al. (1973) stated that the object was visible only on a blue and on a yellow plate taken in immediate succession on 1971 August 26. van den Bergh et al. (1973) suggested that the variable might be either a supernova or a flare star. Although van den Bergh et al. (1973) did not give the brightness of this object, it was estimated to be 12.5 from their figure by Romano (1977).

Sharov (1973) examined plates taken in the Crimean Station of Sternberg Astronomical Institute and Latvian Radio Astrophysical Observatory. Sharov (1973) succeeded in obtaining one observation near the maximum and the light curve of the fading part. Sharov (1973) noted the presence of a star of 21–22 mag on Palomar Observatory Sky Survey (POSS). Based on the large amplitude exceeding 8 mag, rapid fading (0.2 mag d^{-1}) in the early fading part and the very slow (less than 0.001 mag d^{-1}) fading rate in the late fading part, Sharov (1973) stated that the star was unlikely a supernova or a flare star. The light curve, however, did not resemble those of typical novae or dwarf novae and Sharov (1973) suggested that it might be a very distant nova (i.e. intergalactic nova) if it was indeed a nova.

Romano (1977) examined Asiago plates and presented a rough light curve of the outburst (probably unaware of the work by Sharov 1973). Romano (1977) indicated that the variable was at the limit of visibility (∼20.5 mag) on POSS and that color was almost white. Romano (1977) excluded a flare star based on the light curve and also a supernova based on the absence of a galaxy near the star. Romano (1977) concluded that this object is probably a dwarf nova of UV Per type.[1]

Following Romano (1977), Meinunger (1977) studied Sonneberg plates (probably also unaware of the work by Sharov 1973) and constructed a light curve. Meinunger (1977) concluded that the star was clearly a fast nova and could not be a supernova due to the absence of a galaxy near the star. Meinunger (1977) excluded a long-period dwarf nova (like UV Per) based on the facts: (1) the amplitude was larger than 8 mag [Meinunger (1977) even suggested that the object on POSS was a unrelated one], (2) the decline after the maximum was too

[1] UV Per was considered to be the prototype of dwarf novae with large-amplitude and rare outbursts at that time (cf. Petit 1960). WZ Sge was considered as a recurrent nova and the concept of WZ Sge-type dwarf novae was not present. See Kato (2015) for a modern review of WZ Sge-type dwarf novae.

Table 1: Observations of the 1971 outburst of LS And.

JD*	mag†	source‡	JD*	mag†	source‡	JD*	mag†	source‡
179	[19.0	3	223.497	18.30	2	292	[19.0	3
183.468	[20.0	2	224.511	18.56	2	294	[19.0	3
183.508	[13.6	5	225.541	18.30	2	296	[19.0	3
187.479	12.7:	5	235	18.5	3	298	[19.0	3
187.508	11.7:	5	236.248	18.80	2	300	19.0:	3
190	12.5	1	237.261	18.83	2	302	19.0	3
191	13.8*	4	238.405	18.83	2	304	19.0	3
191.504	13.60	2	239.392	18.83	2	305.304	18.83	2
193	14.0*	4	240	18.7	3	308	19.0	3
193.476	14.1:	5	240.407	18.83	2	320	19.0:	3
193.507	14.1:	5	242	18.7	3	324	19.0	3
195.492	14.5::	5	245	18.5	3	332	[19.0	3
195.515	14.5::	5	245.339	19.0	2	335.238	18.8:	2
208	15.85	4	246.254	18.83	2	353.24	19:	2
209	14.9	3	249	18.5	3	570.392	19.2:	2
209.359	15.80	2	249.276	[18.8	2	575.408	19.2:	2
210	16.25	4	252.434	18.8:	2	655.286	[18.3	2
210.499	15.98	2	254.519	[18.3	2	681.291	19.0	2
212	16.4	3	263	18.5:	3	682.168	[19.2	2
213.486	17.54	2	266.367	18.8	2	684.233	19.4	2
214	17.6*	4	268.427	18.83	2	685.201	[19.2	2
215	17.8*	4	271	19.0	3	688.219	19.4	2
217	18.0*	4	276	[19.0	3	983	20.0:	5
217.367	18.30	2	276.284	18.83	2	987	20.0:	5
220.358	18.33	2	277.396	18.8:	2	2105	20:	5
221.545	18.38	2	278.308	18.9	2			
222.4	18.43	2	280	[19.0	3			

* JD−2441000.
† [upper limits. : uncertain. * eye estimate from the published figure.
‡ 1: van den Bergh et al. (1973), 2: Sharov (1973), 3: Romano (1977), 4: Meinunger (1977), 5: Sharov and Karimova (1978).

fast and (3) no further outbursts were observed. Meinunger (1977) suggested that this object was probably a very bright nova in the halo of M 31.

Sharov and Karimova (1978) and his colleagues examined materials and found new records during the outburst close to the maximum in the collection of Odessa Observatory. Precise astrometry of the outbursting object using the materials at Latvian Radio Astrophysical Observatory indicated the identity with the object on POSS. Based on the large (9 mag) amplitude, exceeding those of dwarf novae, Sharov and Karimova (1978) considered that the object should be regarded as a fast nova despite its small amplitude for a nova. Sharov and Karimova (1978) also remarked that the supposed nova did not follow the maximum magnitude relation with decline time for M 31 novae (Sharov 1989), and suggested that either the relation was broken or the object was an intergalactic nova 100–150 kpc from the Sun. This classification by Sharov and Karimova (1978) was adopted in Duerbeck (1987) and LS And was classified as a fast nova in General catalogue of variable stars (GCVS: Kholopov et al. 1985). In GCVS version 4.2 for extragalatic variables, LS And was also given a name M31V0002 probably reflecting the possibility of an object in M 31.

Although most professional astronomers considered or treated LS And as a nova (Downes and Shara 1993; Szkody 1994; Collazzi et al. 2009; Evans et al. 2014; Özdönmez et al. 2018), and some suspected to be an X-ray nova (Rosenbush 1999) or a recurrent nova (Duerbeck 1988; Pagnotta and Schaefer 2014), I may have been the first to become confident that this should be a large-amplitude dwarf nova after knowing this object in the freshly published work by Duerbeck (1987). A part of the atmosphere in the late 1980s among amateur

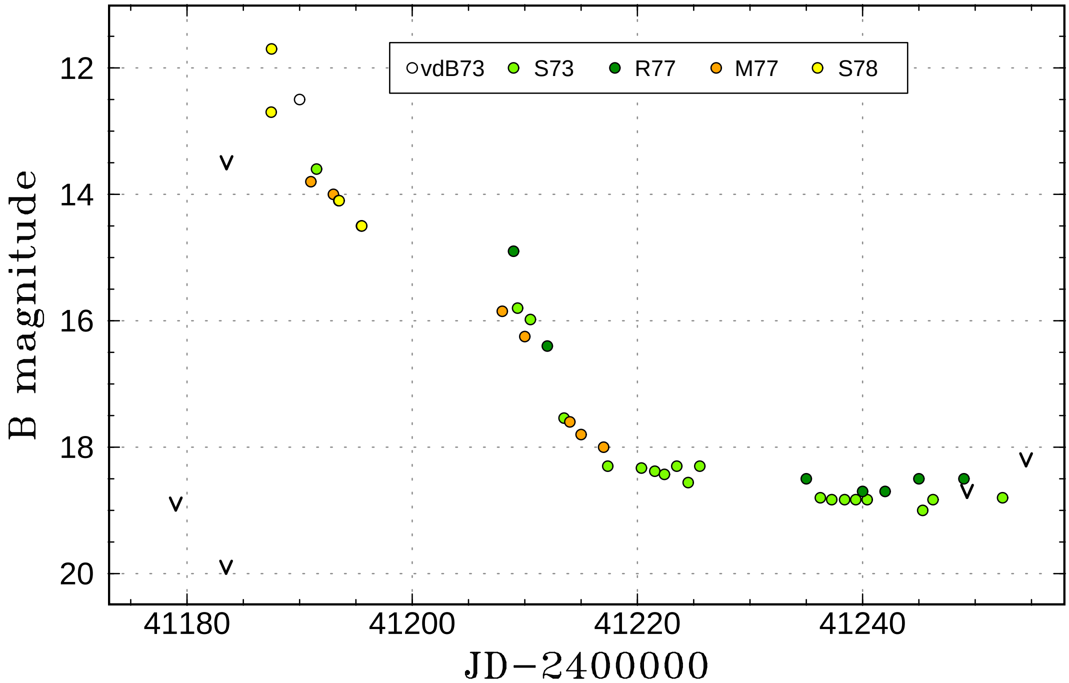

Figure 1: Light curve of the 1971 outburst of LS And using the data in table 1. The sources are vdB73 (van den Bergh et al. 1973), S73 (Sharov 1973), R77 (Romano 1977), M77 (Meinunger 1977) and S78 (Sharov and Karimova 1978). The "v" symbols represent upper limits.

astronomers was already told in Kato (2022a). Visual monitoring of LS And for a new outburst already started in 1987 by VSOLJ members, and then by observers around the world. Although results have not been fruitful for decades [now exceeding 6000 observations without detecting an outburst in the American Association of Variable Stars (AAVSO)[2]; I myself had more than 200 non-detection visual observations when I was an amateur astronomer], I consistently considered LS And as a candidate WZ Sge star (Kato et al. 2001, 2002). I expected that the Gaia satellite would clarify the nature of LS And, but there was no parallax information in Gaia DR2 (Gaia Collaboration et al. 2018). The blue color (Gaia $B-R$=+0.25) and a large proper motion were, however, sufficient to convince me of the dwarf nova-type nature. The parallax in Gaia EDR3 (Gaia Collaboration et al. 2021) was not conclusive, probably due to the faintness of this object. The color in Gaia EDR3 was even bluer ($B-R$=−0.06).

The "moment" arrived like lightening when I was examining light curves obtained by the Zwicky Transient Facility (ZTF: Masci et al. 2019)[3]. It was when I started examining light curves of recent ZTF data. As usual, I was looking at the table of dwarf novae listed in alphabetical order, and almost unconsciously typed LS And (as a matter of fact, I already did not pay special attention to this object regularly since I knew that it had been well monitored by amateur observers and considered that no missed outburst would be expected in the ZTF data). The reason why I specially selected LS And was unknown, but the light curve on the display was a familiar one of a WZ Sge star. I initially considered that I entered a name of a different well-known WZ Sge star (almost unconsciously as a routine work), but realized that it was "LS And". Unthinkable! I initially could not believe my eyes, but it was indeed LS And and I almost automatically issued vsnet-alert 27267[4], even without sufficient patience for waiting the result of a query to the All-Sky Automated Survey for Supernovae (ASAS-SN) Sky Patrol data (Shappee et al. 2014; Kochanek et al. 2017). My emotion at that time may have been similar to a situation when I encountered a rare bird which I could not believe (cf. Kato 2022a). Birders will agree.

In the world of birders, it must have become the busiest moment after any discovery — one needs to locate

[2]<http://www.aavso.org/data-download>.

[3]The ZTF data can be obtained from IRSA <https://irsa.ipac.caltech.edu/Missions/ztf.html> using the interface <https://irsa.ipac.caltech.edu/docs/program_interface/ztf_api.html> or using a wrapper of the above IRSA API <https://github.com/MickaelRigault/ztfquery>.

[4]<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/27267>.

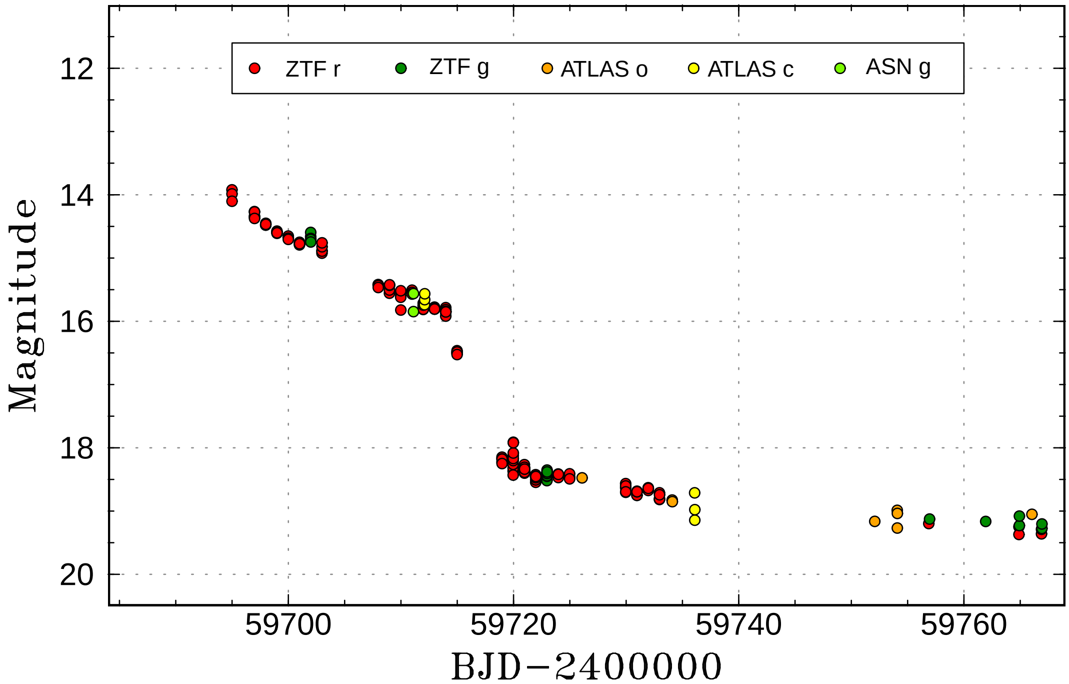

Figure 2: Light curve of the 2022 outburst of LS And using ZTF, ATLAS and ASAS-SN data. There were no upper limit observations before the initial detection.

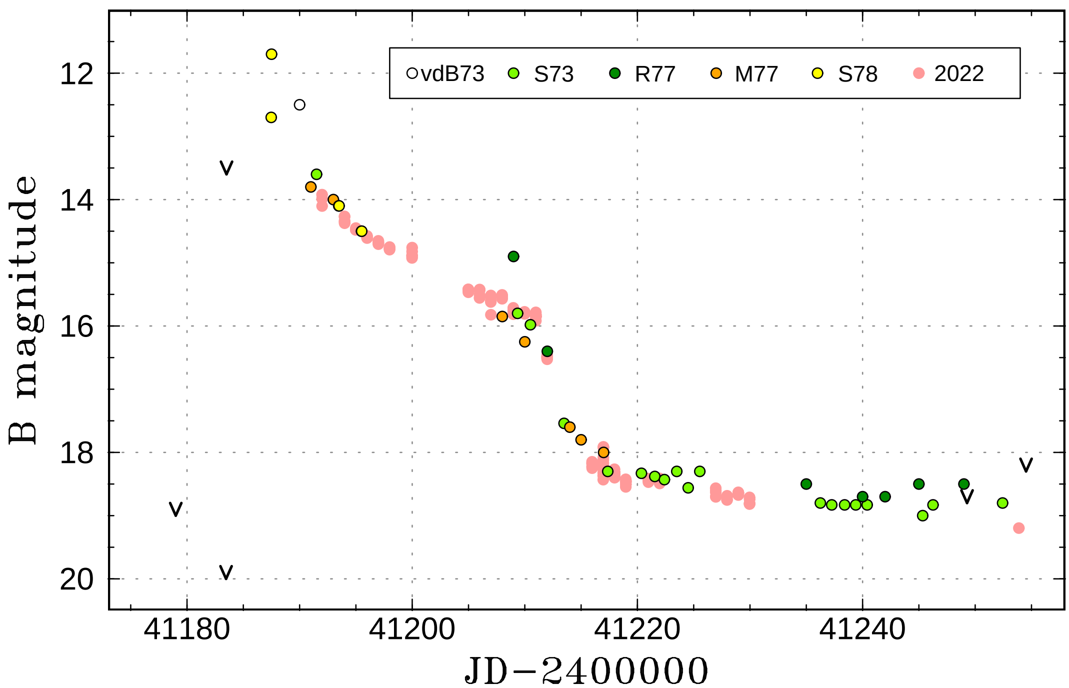

Figure 3: Comparison of light curves of the 1971 and 2022 outburst of LS And. The symbols for the 1971 observations are the same as in figure 1. The 2022 data (ZTF r magnitudes) were shifted by 18503 d.

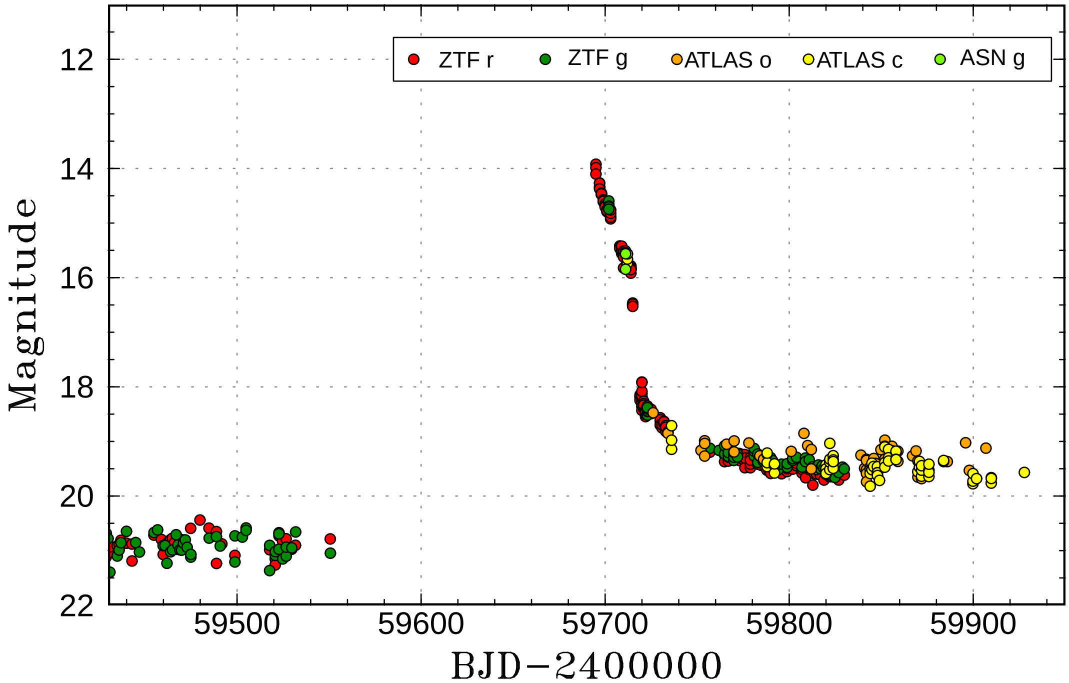

Figure 4: Long-term light curve of the 2022 outburst of LS And. The symbols are the same as in figure 2.

the bird and take images or recordings sufficient for a proof of the existence of a rare bird. The case for the detection of the 2022 outburst of LS And was different. There was no special care for preserving the data shown on the display, and I went to the library (fortunately very close) to search the light curve of the 1971 outburst, which still stayed deep in my memory even after decades.

So it's time to return to science. In table 1, I summarized photometric data for the 1971 outburst. The magnitudes were all photographic (equivalent to B). Magnitudes with * were estimated by my eyes from the figure in Meinunger (1977), which are probably correct to ±1 d and ±0.1 mag. The magnitude for JD=190 was similarly estimated from a published figure by Romano (1977). Meinunger (1977) claimed that the object was estimated too bright by Romano (1977). The light curve drawn from these data is presented in figure 1. This is not much different from the one published in Sharov and Karimova (1978), but is worth presenting here since Sharov and Karimova (1978) is difficult to reach.

The 2022 light curve is shown in figure 2. It is very clear that the 1971 and 2022 light curves are very similar: plateau-type fading lasting for ∼20 d followed by rapid decline and subsequent slow fading. They are typical WZ Sge-type outbursts without rebrightening (type D superoutburst in Kato 2015). It is also well-known that the same WZ Sge star tends to repeat the same type of rebrightening (Kato 2015) and LS And is also the case. Although the mechanism of rebrightening(s) is not yet well understood, empirical relationship shows that WZ Sge stars without rebrightening are mostly objects near the period minimum of cataclysmic variables, but before reaching it (figure 17 in Kato 2015). The orbital period of LS And is thus expected to be within 0.053–0.060 d. The fading rate of the plateau phase (BJD 2459696–2459714.5) was 0.089(1) mag d^{-1}, which corresponds to $\log t_{\rm d}$=1.05, a typical value for a WZ Sge star without rebrightening and not resembling a period bouncer (see figure 87 in Kato et al. 2014). A comparison between the 1971 and 2022 outbursts is shown in figure 3 (from now on, I treat all photometric bands in visual wavelengths almost identical with V, which is a good approximation for a WZ Sge star in outburst). These outbursts were almost exactly the same and the interval of these two outburst was 18503 d (=50.66 yr). This comparison suggests that the 2022 outburst would not have started before JD 2459682 (2022 April 12). Definitely a sigh! (particularly for amateur observers) considering the almost no evening visibility of this object in mid-April.

People may wonder if these outburst could be those of an SU UMa star rather than a WZ Sge star, and how I can be confident about the classification without observation of early superhumps (cf. Kato 2015). I show a long-term light curve of the 2022 outburst in figure 2. The object was brighter by 1.5 mag after the outburst. The post-outburst phenomenon is a long fading tail, which is characteristic to a WZ Sge-type outburst and not seen in an SU UMa star. The presence of the same phenomenon was also reported after the 1971 outburst (Sharov 1973).[5] Before the outburst plateau, there was a phase with more rapid fading (more evident in the 1971 light curve and only one day in the 2022 one). This feature is commonly seen in WZ Sge-type outbursts and is referred to as a viscous decay phase. Early superhumps are expected during this phase if the binary has a sufficient inclination (Kato 2015, 2022b).

The peak magnitude probably requires re-examination. Although most literature gives 11.7 mag as the maximum for LS And, it is evident from table 1 that this magnitude was uncertain (":" usually means that the object is close to the limit of photographic materials or the quality of the photograph is poor) and was the brighter one of two uncertain observations (11.7 and 12.7 mag) only 40 min apart. It looks more likely that the true brightest observation was close to their average (12.2 mag). The outburst amplitude based on this value is 8.8 mag using the ZTF data before the 2022 outburst. The true peak would have been brighter, though, since there was a 4 d observational gap before the first observation of the outburst (but see the discussion below).

As seen from the 2022 observations, the magnitude when ordinary superhumps should appear following the viscous decay phase was 14.3 mag. In ordinary WZ Sge stars, the absolute magnitude (M_V) when ordinary superhumps appear is +5.4 (for an average inclination of 1 radian) (Kato 2022b). Using this value as the standard candle, the distance modulus of LS And is estimated to be 8.9. The observed peak (12.2 mag) in 1971 corresponds to M_V=+3.3. The quiescent magnitude (21.0 mag, ZTF data) corresponds to M_V=+12.1. The difference (6.7 mag) between quiescent magnitude and the magnitude when ordinary superhumps appear is typical for a (non-period bouncer) WZ Sge star (see fig. 23 in Kato 2015; Tampo et al. 2020). Other properties of LS And are expected to be similar to those of typical WZ Sge stars.

The detection of the 2022 outburst of LS And brought a some kind of despair to observers who had been expecting to see a fresh outburst for decades. Could there be a possibility that LS And silently underwent outbursts more frequently only around solar conjunctions? This was indeed the case of the SU UMa star VY Aqr located close to the ecliptic. Despite the mean interval of superoutbursts of less than 2 yr, this object was not recorded in superoutburst between 1994 and 2006, and between 2008 and 2020. It was most likely that superoutbursts in this object occurred around solar conjunctions and were not recorded. Although similar things may have happened in LS And at least in the past, modern deep observations such as ZTF should have detected the object during a fading tail if there was a missed superoutburst. There was no indication of such a detection in the ZTF data since 2018, and the outburst interval should be longer than 5 yr. The fading tail lasted more than a year (Sharov 1973). Sharov and Karimova (1978) described that the object returned to practically the same level before the outburst after 5.5 yr, although this description may have assumed a nova-type light curve and could have overestimated the duration of the fading tail. Considering these values and considering that parameters of LS And are similar to those of typical WZ Sge stars, the next major outburst would be expected after a decade or even more [see figure 5 in Kato (2015) for the distribution of outburst intervals in WZ Sge stars]. By comparing the recorded peak M_V=+3.3 (in 1971) with the statistics of known WZ Sge stars (figure 10 in Tampo et al. 2020), it appears that the true peak in 1971 was not missed after a considerable delay (i.e. the object was unlikely to have reached 11.0 mag even at the true peak). The next superoutburst would also be around 12.2 mag. There are, however, exceptional objects like V3101 Cyg (Tampo et al. 2020; Hameury and Lasota 2021) and there may be an unexpected phenomenon even after the outburst. In the post-outburst data of LS And, 0.5 mag brightening lasting for 10–20 d and starting around JD 2459852 was present (figure 3). This might suggest that LS And is still active in the post-superoutburst phase and would be worth observing before it finally returns to quiescence.

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[5]It might be interesting to leave a remark that the figure in Sharov (1973) dealt with this phenomenon rather than the shape of the outburst. Please have a look at his figure if you have a chance too see this reference.

of Taiwan, the University of Wisconsin at Milwaukee, and Lawrence Berkeley National Laboratories. Operations are conducted by COO, IPAC, and UW.

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LS And, VY Aqr, V3101 Cyg, UV Per, WZ Sge, SU UMa, M 31, M31V0002

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