

LMC S154: the first Magellanic symbiotic recurrent nova^{★,★★}

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ABSTRACT

Classical nova outburst has been suggested for a number of extragalactic symbiotic stars, but in none of the systems has it been proven. In this work we study the nature of one of these systems, LMC S154. We gathered archival photometric observations in order to determine the timescales and nature of variability in this system. Additionally we carried out photometric and spectroscopic monitoring of the system and fitted synthetic spectra to the observations. Carbon abundance in the photosphere of the red giant is significantly higher than that derived for the nebula, which confirms pollution of the circumbinary material by the ejecta from nova outburst. The photometric and spectroscopic data show that the system reached quiescence in 2009, which means that for the first time all of the phases of a nova outburst were observed in an extragalactic symbiotic star. The data indicate that most probably there were three outbursts observed in LMC S154, which would make this system a member of a rare class of symbiotic recurrent novae. The recurrent nature of the system is supported by the discovery of coronal lines in the spectra, which are observed only in symbiotic stars with massive white dwarfs and with short-recurrence-time outbursts. Gathered evidence is sufficient to classify LMC S154 as the first bona fide extragalactic symbiotic nova, which is likely a recurrent nova. It is also the first nova with a carbon-rich donor.

Key words. binaries: symbiotic – stars: individual: LHA 120-S 154 – novae, cataclysmic variables

1. Introduction

Symbiotic stars (SySts) are interacting binaries with orbital periods ranging from hundreds of days to decades (Gromadzki et al. 2009, 2013). In these systems matter is transferred from a red giant (RG) to a compact companion, typically a white dwarf (WD). The matter could be transferred through a Roche-lobe overflow or wind accretion. Symbiotic stars are classified as D-type (*dust*) systems when the mass donor is a Mira embedded in a dense nebula. In S-type (*stellar*) systems there is a normal RG as a mass donor (see Mikołajewska 2012 for a recent review).

Symbiotic novae (SyNe) are SySts in which the WD has experienced a thermonuclear explosion on its surface. They form a small subclass of classical novae and are very rare among SySts. There are two kinds of SyNe. In typical SyNe the outburst occurs on a medium-mass WD and is relatively quiet. In the case of a massive WD accreting at a high rate the outburst is faster and has a higher amplitude. These outbursts are typically observed more than once, hence they are classified as symbiotic recurrent novae (SyRNe). Thus far, only four SyRNe have been identified (T CrB, V745 Sco, V3890 Sgr and RS Oph), which makes this

class of systems extremely rare. A recent review of the outburst activity of SySts is presented in Mikołajewska (2010).

Nine SySts have been discovered in the Large Magellanic Cloud (LMC) and several dozen SySts were discovered outside of the Milky Way in general (Belczyński et al. 2000; Gonçalves et al. 2008; Kniazev et al. 2009; Miszalski et al. 2014; Mikołajewska et al. 2014; Hajduk et al. 2015; Iłkiewicz & Mikołajewska 2017; Iłkiewicz et al. 2018a,b). Outbursts of Z And-type, which are thought to be caused by increased mass transfer onto a WD, have only been observed in the cases of two extragalactic SySts: LIN 9 (Miszalski et al. 2014) and LHA 120-S 63 = LMC S63 (Iłkiewicz et al. 2015). Classical nova outburst has not been proven for any of the extragalactic SySts.

LMC S154 = LHA 120-S 154 = NSV 16200 was an X-ray source located in the LMC observed during a High-Energy Astronomy Observatory (HEAO) 1 survey (Wood et al. 1984) between August 15 1977, and February 15 1978. Remillard et al. (1992) failed to detect the object in EXOSITE satellite observations from October 1984. LMC S154 has not been detected in X-rays since that time. Remillard et al. (1992) carried out optical observations of the object. The observations carried out during the period from February 2 1984, to February 21 1988, showed that the spectrum of the object was characterized by a flat continuum, strong Balmer-series emission lines, and the presence of some low-excitation emission lines. In observations from December 16 1988, LMC S154 showed a changed spectrum characterized by high-excitation emission lines typical

* Tables A.1 and A.2 are only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/viz-bin/qcat?J/A+A/624/A133>

** Based on observations made with the Southern African Large Telescope (SALT) under programme 2015-2-SCI-036

for a SySt. Photometric observations of Remillard et al. (1992) showed variability with an amplitude of ~ 4 mag on a timescale of decades.

The variability of LMC S154 resembles that of SyNe such as for example RX Pup and PU Vul (Remillard et al. 1992; Vogel & Morgan 1994). Vogel & Morgan (1994) measured overabundance of nitrogen in the nebula around the system, which supports classical nova outburst in the recent history of the system. Muerst et al. (1996) detected a C-rich giant in the spectrum of LMC S154 for the first time, which proves the symbiotic nature of the system. The authors derived the spectral type of the cool component to C2.2. Mikołajewska (2004), on the other hand, suggested that the system was of D-type. The SyN nature of the system has had not yet been confirmed, mainly because of a significant gap in photometric observations published by Remillard et al. (1992) ranging from the 1950s to 1980s that hinders estimates of the timescale of its variability. Moreover, the system has not yet been observed in quiescence.

In this work we study the possible evidence for the nova outburst of LMC S154. We present results of our spectroscopic and photometric survey supplemented with collected archival observations in Sect. 2. The timescale of outburst(s) activity of the system is analyzed in Sect. 3.1. The discovery of coronal lines in the system is discussed in Sect. 3.2. The variability during quiescence is investigated in Sect. 3.4. The physical parameters of the cool component are studied in Sect. 4. The evolution of WD parameters during the most recent outburst is presented in Sect. 5. Arguments supporting the SyN nature of the system are presented in Sect. 6.

2. Observations

2.1. Spectroscopy

We carried out spectroscopic monitoring of LMC S154 using the 1.9 m telescope at the South African Astronomical Observatory (SAAO). The telescope was mounted with the SITE (Scientific Imaging Technologies, INC.) CCD together with a grating spectrograph. The instrumental setup included grating #7 with 300 lines per millimeter and a slit width of $1.5''$. The resulting resolving power was $R \approx 1000$. The covered spectral range varied with every observation, but approximately covered a range of 3800–7700 Å.

Another low-resolution spectrum was carried out with the Southern African Large Telescope (SALT; Buckley et al. 2006; O'Donoghue et al. 2006) equipped with the Robert Stobie Spectrograph (RSS; Burgh et al. 2003; Kobulnicky et al. 2003) and PG900 grating. Observations were obtained under programme 2015-2-SCI-036 (PI: Mikołajewska). LMC S154 was observed in two wavelength ranges giving the combined covered wavelength range of ~ 3900 – 8250 Å.

The spectra obtained using SALT and SAAO 1.9 m telescopes were reduced using the standard IRAF procedures. Spectra were flux-calibrated using spectrophotometric standards. Due to slit losses in SAAO 1.9 m data, as well as the variable pupil design of SALT precluding absolute spectrophotometric calibration, we scaled the flux scale of our spectra to the known V -band photometry near the epoch of observation. The list of spectroscopic observations is presented in Table 1. The spectra are presented in Fig. 1.

We measured fluxes of emission lines by fitting a Gaussian profile. In the case of lines that could not be fitted by a Gaussian profile we integrated the flux above the local continuum. The main source of uncertainty was choosing the local con-

Table 1. Log of spectroscopic observations.

Date	MJD	Telescope	Exposure (s)
2005-11-19	53693	SAAO 1.9 m	3×1800
2006-10-07	54015	SAAO 1.9 m	3×1800
2007-10-20	54393	SAAO 1.9 m	3×1200
2008-10-31	54770	SAAO 1.9 m	3×1200
2009-10-31	55135	SAAO 1.9 m	3×1200
2015-10-28	57323	SALT	$2 \times 60, 2 \times 1800$

tinuum level. Typical uncertainty was of the order of 15% in the case of the strongest lines, and 30% in the case of weakest. The measurements are presented in Table 2 and Fig. 2.

Additionally we employed two International Ultraviolet Explorer (IUE) spectra. The spectra were sp40907 carried out February 2 1991 and sp47766 carried out May 29 1993. The spectra are presented in Fig. 3.

2.2. Photometry

Photometric monitoring of LMC S154 was carried out with a 35 cm Meade RCX400 telescope at the Kleinkaroo Observatory. The instrumental setup included the SBIG ST8-XME CCD camera and V and I_c filters. Observations from each night were reduced and stacked in a standard fashion. The photometry was carried out with the single image mode of the AIP4 image-processing software. The accuracy of the derived magnitudes is better than 0.1 mag.

Additionally we observed LMC S154 in V filter with a 2.5 m Irene du Pont telescope SIT e2K-1 camera at the Las Campanas observatory. Data reduction was performed using standard procedures in IRAF. We employed the brightest stars in the field with magnitudes from the Southern Proper Motion program (SPM4; Girard et al. 2011) as standard stars.

We supplemented our photometry with collected photometric observations from the literature. The magnitudes are presented in Table A.1, Figs. 4 and 5.

We retrieved publicly available UV images containing LMC S154 taken by the *Swift* UV optical telescope (UVOT; Gehrels et al. 2004) from the UK *Swift* Science Data Centre (UKSSDC)¹. Observations were available only in the UV filter UVM2 centered at $\lambda 2246$ Å (see Poole et al. 2008). We followed the UVOT data analysis guide of the UKSSDC to perform aperture photometry on the images using the heasoft-6.18 software² and the latest caldb files for *Swift*. Optimal aperture sizes were chosen based on the filter and pixel binning according to Poole et al. (2008). Each image was inspected before calculating the magnitudes to ensure the correct object was in the defined aperture. Table A.2 gives a log of the observations where the magnitudes are provided in the Vega system. The data are presented in Fig. 4.

3. Results

3.1. Timescale of outburst(s)

There is a substantial gap in the photometric observations presented by Remillard et al. (1992). The gap ranges from the

¹ <http://www.swift.ac.uk/index.php>

² <http://heasarc.gsfc.nasa.gov/lheasoft>

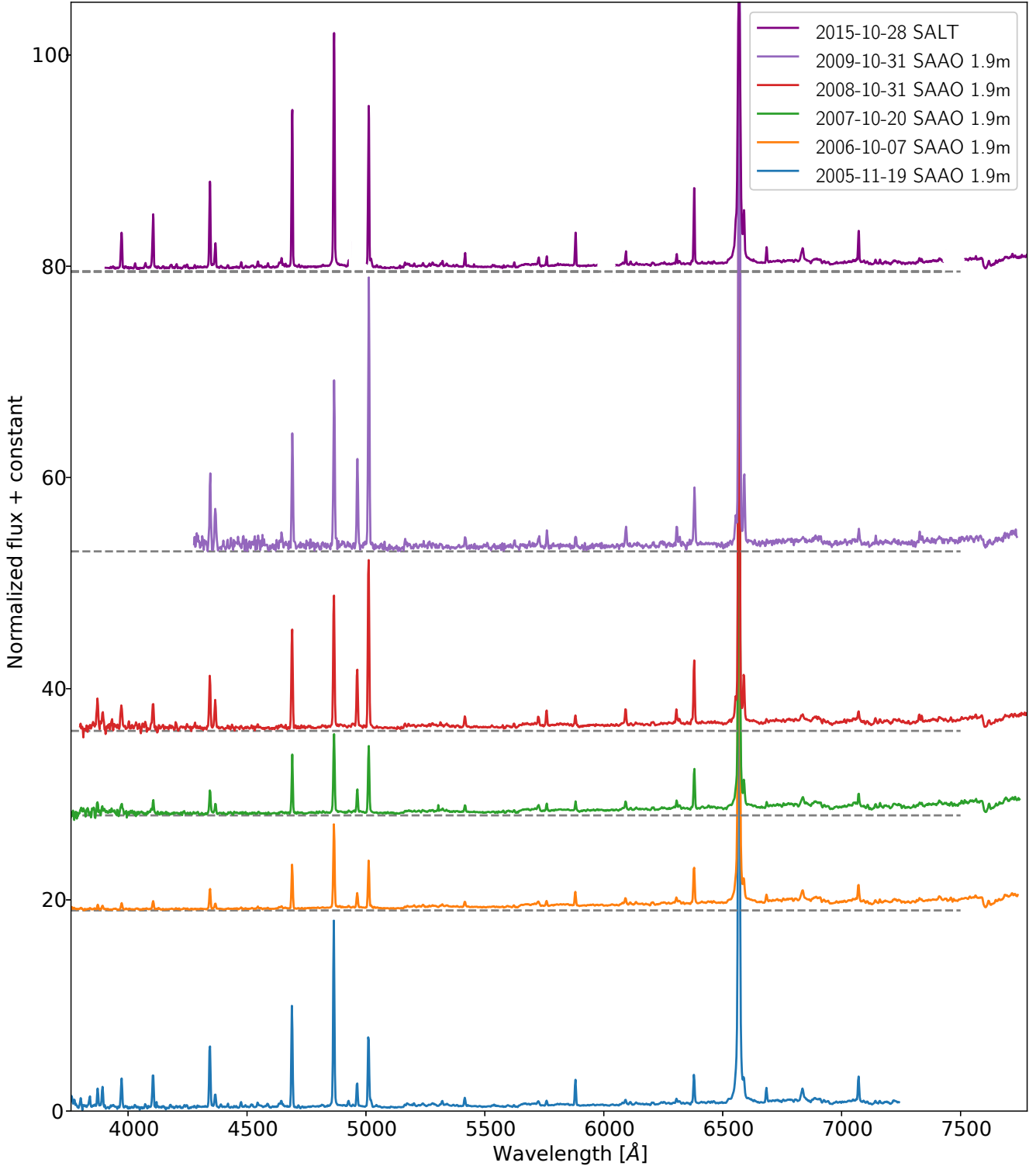


Fig. 1. Spectral variability of LMC S154. The spectra have been normalized in wavelength range 6700–6800 Å.

1950s to the 1980s which hinders the determination of whether the active phases of LMC S154 in the 1940s and 1980s is the same outburst or a two separate events. The archival observations presented in Table A.1 show that in 1975–1976 LMC S154 was at $m_{\text{pg}} \approx 14.8$ mag. This corresponds to the magnitude during an active phase of the system (Remillard et al. 1992), hence the last observed active phase started in the 1970s at the latest.

Interestingly, the spectrum of LMC S154 obtained by Lindsay & Mullan (1963) revealed [O III] lines and no continuum. While Lindsay & Mullan (1963) did not give a date for the observation, most of the data collected for their survey were collected in two seasons in 1956 and 1960 (McFarland et al. 1975), at the beginning of the gap in photometric observations. The presence of [O III] in the 1950s, and the similarity of spectra observed by Lindsay & Mullan (1963) and

Table 2. Observed wavelength from SALT spectrum and relative fluxes of emission lines.

	Date	2005	2006	2007	2008	2009	2015
	MJD	53693	54015	54393	54770	55135	57323
ID	$\lambda_{\text{observed}} (\text{\AA})$	$100 \times \text{Flux} / \text{Flux}(\text{H}\beta)$					
[Ne III] 3869	3871.04	10	5		26		
H δ , He I	3892.73	12	5		17		
H ϵ	3971.61	17	8		20		15
H δ	4104.50	20	10	15	20		21
H γ	4343.67	35	24	31	40	39	33
[O III] 4363	4366.14	8	7	12	21	31	11
He II 4686	4689.46	54	51	61	76	66	59
H β	4865.15	100	100	100	100	100	100
[O III] 4959	4962.98	12	17	26	42	52	
[O III] 5007	5010.90	41	55	83	130	152	60
He II 5412	5416.11	5	7	8	9	6	5
[N II] 5755	5759.26		6	7	11	9	3
He I 5876	5880.54	13	16	10	8	7	11
[Fe VII] 6086	6091.67		8	11	12	12	5
[O I] 6300	6305.21			6	11	11	3
[Fe X] 6375	6379.89	16	46	49	48	34	28
H α + [N II] 6548	6568.66	661	1012	1000	616	536	
[N II] 6584	6589.26	9	21	29	34	46	31
He I 6678	6683.70	8	8	5			6
O VI 6825	6835.45	15	19	19			10
He I 7065	7070.96	15	18	12			10
[Fe XI] 7892	7897.56						7
	V^* (mag)	15.60	15.95	15.90	16.40	16.60	16.35
	Flux (H β) (10^{-13} erg s $^{-1}$ cm $^{-2}$)	3.8	3.6	2.1	1.5	4.4	2.36

Notes: (*) Assumed magnitude used for scaling of the spectra.

Remillard et al. (1992), suggest that Lindsay & Mullan (1963) observed LMC S154 at the nebular phase at the end of outburst, and there were at least two outbursts recorded in the history of LMC S154, one with a maximum in the 1940s–50s and the second with a maximum in the 1970s–80s. This makes LMC S154 a member of a rare class of SyRNe. Moreover, in the 1890s, despite the scarcity of observations, it seems that the star experienced a drop from $m_{\text{pg}} \approx 14$ mag, a value similar to the one observed at the nova maximum, to $m_{\text{pg}} \approx 17$ mag observed in quiescence (Fig. 5). Therefore it is likely that a drop from maximum of an even older nova outburst was observed at the end of the nineteenth century.

In 2009 the system stopped fading and now shows similar B magnitude to that seen in the 1910s (Fig. 5). This means that the system finally reached quiescence and the outburst that started in 1970s lasted at least ~ 40 yr. The $H\alpha/H\beta$ ratio was gradually decreasing in the observations of Remillard et al. (1992), while LMC S154 was going out of outburst, and the $H\alpha/H\beta$ ratio on all of our spectra is in agreement with the latest spectra of Remillard et al. (1992). This supports the idea that Remillard et al. (1992) observed the start of the transition to quiescence. The ~ 40 yr timescale of outburst is consistent with approximately two outbursts per century. This also implies a period of ~ 10 – 20 yr in quiescence after an outburst. This period is consistent with the observed quiescence in the 1900s and 1910s between two outbursts (Fig. 5).

3.2. Coronal lines

The [Fe VII] 6086, [Fe X] 6375, and [Fe XI] 7892 coronal lines are present in our spectra (see Table 2). [Fe X] and [Fe XI] lines are

detected for the first time in LMC S154, while the [Fe VII] 6086 line appears to be present in the archival spectra, but was not discussed by authors (see Fig. 6). The [Fe X] and [Fe XI] coronal lines are very rare in SySt in general (see e.g., Jordan et al. 1996; Mikołajewska et al. 2014), but are more common in novae during a nebular phase (Williams 2012) and in supersoft X-ray sources (SSXS), where there is stable hydrogen burning on the surface of the WD (e.g., SMC 3; Jordan et al. 1996). Therefore, the presence of [Fe X] and [Fe XI] lines in SySt is always associated with nuclear reactions on the surface of WDs.

The [Fe X] 6375 line is observed during the SSXS phase of a nova outburst, when nuclear burning is still continuing (MacDonald et al. 1985; Krautter & Williams 1989). Hence, the [Fe X] 6375 line is well correlated with soft X-ray flux, both in SyNe (Shore et al. 2012) and in classical novae (Moro-Martín et al. 2001). Therefore, it is expected that in LMC S154 the X-ray emission should be the strongest in SSXS phase, around the maximum of [Fe X] 6375 in the 2000s. However, the X-ray emission was detected in the 1970s, and it was not present in the 1980s (Remillard et al. 1992). Since a WD can experience only one SSXS phase during an outburst, this indicates that the X-ray emission in the 1970s was not due to the SSXS phase, but originated in a shock produced by an expanding blast wave (Sokoloski et al. 2006; Drake et al. 2009). This mechanism of radiation is expected at the earliest phase of the nova outburst is therefore a strong argument in support of the idea that the most recent outburst started in the 1970s.

Assuming a distance to LMC of 49.97 kpc (Pietrzyński et al. 2013) a reddening $E(B-V) = 0.17$ mag (Muerseet et al. 1996) and using [Fe X] 6375 flux from the 2015 SALT spectrum we get $L([\text{Fe X}] 6375) = 2.0 \times 10^{34}$ erg s $^{-1}$. Maximum

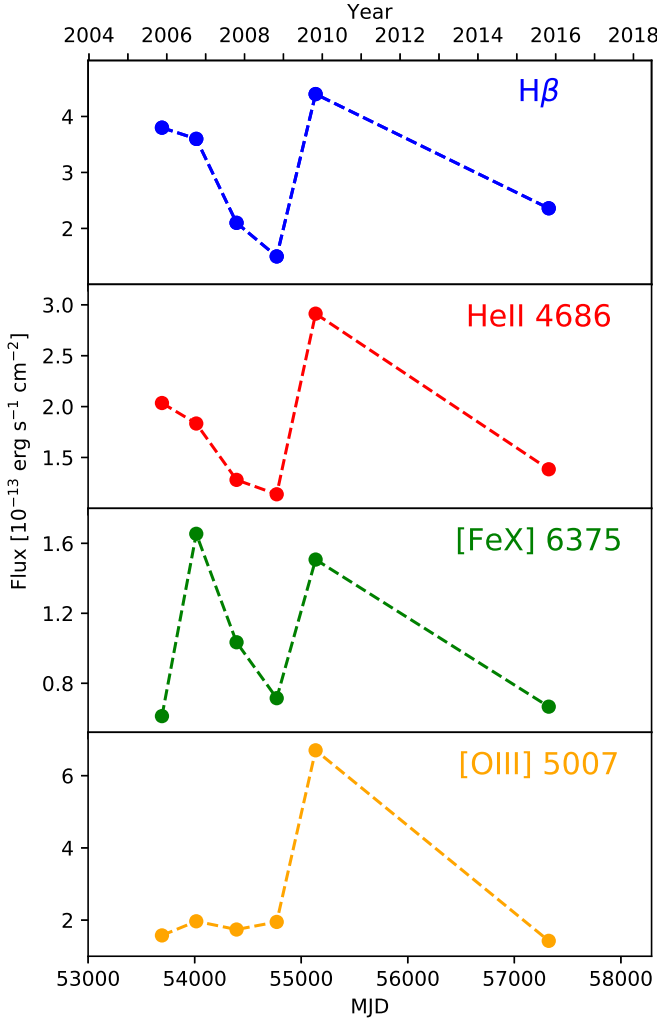


Fig. 2. Variability of emission line fluxes in LMC S154.

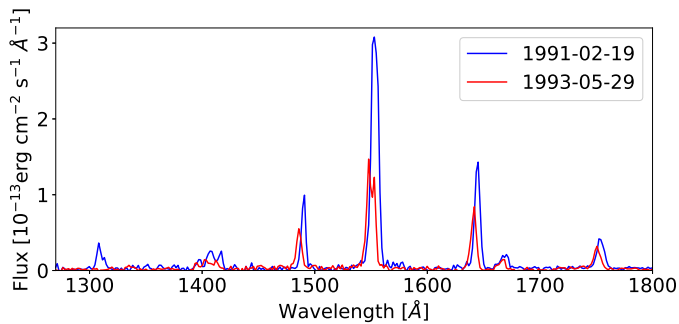


Fig. 3. IUE spectra of LMC S154.

[Fe x] 6375 flux observed during the last outburst of RS Oph was $1.5 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$ (Iijima 2009). Assuming a distance to RS Oph of 1.4 kpc (Barry et al. 2008) and reddening $E(B-V) = 0.69 \text{ mag}$ (Zamanov et al. 2018) this corresponds to a luminosity $L([\text{Fe x}] 6375) = 1.9 \times 10^{35} \text{ erg s}^{-1}$. In SMC 3, an SSXS SySt, the [Fe x] 6375 line was $2.0 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$ (Morgan 1992) which after scaling for reddening $E(B-V) = 0.099 \text{ mag}$ (Hilditch et al. 2005) and SMC distance of 60.6 kpc (Hilditch et al. 2005) gives $L([\text{Fe x}] 6375) = 1.1 \times 10^{34} \text{ erg s}^{-1}$. Given the differences in metallicity and reddening of these objects, one could say that the luminosity of the [Fe x] line in the two

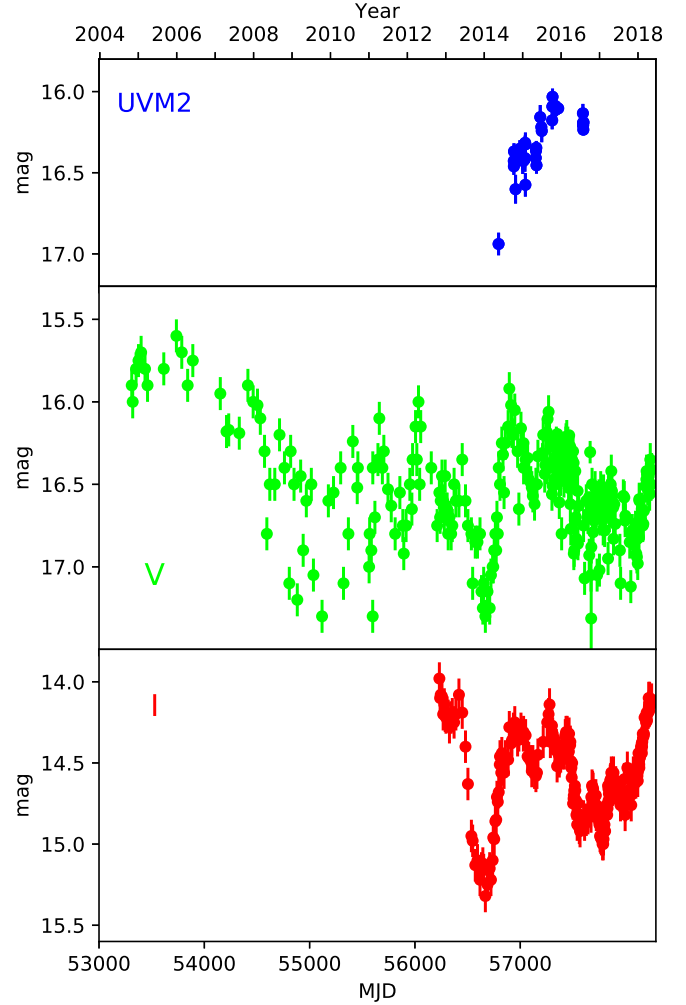


Fig. 4. Most recent photometric variability of LMC S154.

X-ray-bright objects is consistent with [Fe x] luminosity in LMC S154. This confirms that [Fe x] and [Fe xi] emission lines are due to the SSXS phase of outburst.

Given the spectroscopic evolution of LMC S154 in observations of Remillard et al. (1992) the maximum of the nova outburst was most probably no later than their first spectroscopic observation in February 1984. The maximum was probably even earlier given the fact that the star was detected in X-rays in the 1970s. The coronal lines were not present at least until May 1993 (Muerstet et al. 1996) which corresponds to at least 9 years after the maximum. The first spectrum with the [Fe x] 6375 line detected was from 2005, at least 21 years after the maximum. The emission line was still present more than 31 years after the maximum.

Detection of this line so late after outburst is somewhat surprising. Typically in the recurrent novae and SyRNe the [Fe x] 6375 line is detected ~ 1 month after outburst (see e.g., Williams et al. 1991; Iijima 2009) while in classical novae this line can be detected a few years after the maximum (Krautter & Williams 1989). Moreover, in SyNe the [Fe x] 6375 line is observed only in the case of massive WDs that exhibit nova outburst on short timescales; for example in RS Oph (Osborne et al. 2011), V407 Cyg (Shore et al. 2012), and T CrB (Bloch & Mao-Lin 1953). In SyNe, with long timescales and less massive WDs, only [Fe vii] lines are observed; for example in RX Pup (Mikolajewska et al. 1999), AG Peg

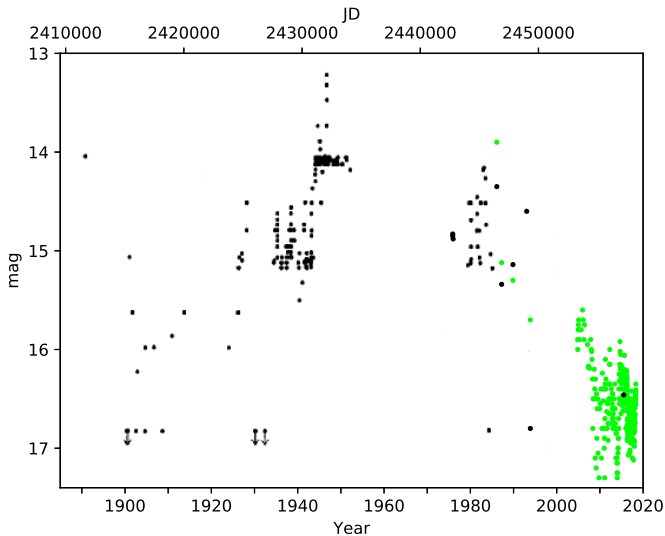


Fig. 5. Historical light curve of LMC S154. The black points are magnitudes in m_{pg} and B filters. The green points are magnitudes in V filter.

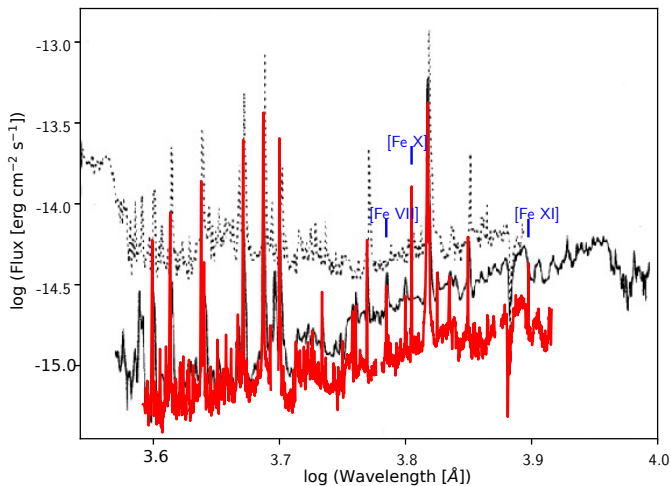


Fig. 6. Comparison of the most recent SALT spectrum of LMC S154 from 2015 (red line) to the spectra obtained by Remillard et al. (1992) in 1989 (black dashed line) and Muerset et al. (1996) in 1993 (black line).

(Kenyon et al. 2001), and PU Vul (Yoo 2007). This suggests that the outburst timescale in LMC S154 was in intermediate range ($\ll 100$ yr) which is consistent with the hypothesis that there were two separate outbursts, one with its maximum in the 1940s–50s and the second with its maximum in the 1970s–80s.

3.3. X-ray and UV emission during outburst

X-ray radiation was detected in LMC S154 between August 15 1977 and February 2 1978 and has not been detected since (Remillard et al. 1992). If there was in fact a nova outburst in the system that came to a halt in the 1990s, the subsequent lack of X-ray radiation is expected. In order to confirm the reality of X-ray radiation in LMC S154 during the outburst we search the High Energy Astrophysics Science Archive Research Center³ (HEASARC) for additional reported observations. The only finding is the reported detection of LMC S154 by the Eighth Orbiting Solar Observatory (OSO-8) on October 14

³ <http://heasarc.nasa.gov/>

1975. The source was detected at 4.7 ± 0.1 counts s^{-1} in the range of 2–60 keV. This observation was before the one reported by (Remillard et al. 1992) and supports the reality of X-ray emission from LMC S154 during the most recent outburst.

Change of emission line fluxes in the two IUE spectra is evident (Fig. 3). Fluxes of all of detected emission lines decreased between 1991 and 1993. This is consistent with the drop in brightness of the system during 1993 (Table A.1). In the spectrum from 1993 the emission lines appear to be narrower. This lead to the separation of C IV 1548 and C IV 1551 lines. A similar drop in the width of emission lines after a nova outburst was observed for example in AG Peg (Kenyon et al. 1993). This is probably related to the fact that these lines are formed in the wind of the WD, which has slowed down after the outburst. Interestingly there is an apparent blueshift of the emission lines in the spectrum from 1993.

3.4. Photometric and spectroscopic variability in quiescence

The outburst of LMC S154 ended in 2009 and the star stopped fading. After the end of the outburst, during 2013 and 2014, LMC S154 showed a dip in its light curve, where the brightness decreased by ~ 1 mag in V and I bands (Fig. 4). After recovery from the dip the *Swift* light curve showed that the star brightened by ~ 1 mag in 1.5 yr (Fig. 4). Similar behavior was observed in V band in RX Pup, where both the dip at the end of the outburst and a subsequent brightening were observed (Mikolajewska et al. 1999). This was interpreted as a signature of ceasing of the hot component wind which allowed for a start of accretion of the cool component wind (Mikolajewska et al. 1999, 2002). Another explanation of brightening in the *Swift* UV observations could be active phases observed in other SyRNe (see e.g., Hkiewicz et al. 2016).

In the most recent observations in V and I bands LMC S154 shows quasi-periodic variability on a timescale of ~ 250 d (Fig. 4). This variability is not present in the *Swift* UVM2 band. The simplest interpretation would be pulsations of the RG. This is consistent with the fact that the system shows variability with an amplitude of ~ 0.5 mag in J and K filters (see Table A.1). Moreover, pulsations would be consistent with the position of the RG on the K versus $(J-K)$ colour-magnitude diagram for LMC (Soszynski et al. 2007).

In the visual spectrum the [N II] emission lines are detected for the first time. They are clearly visible in all of our spectra (Fig. 1). The presence of these lines is typical for a nebular phase after a nova outburst (see e.g., Bode & Evans 2008). Both the [N II] and [O III] nebular lines were roughly constant in the years 2005–2008 (see Fig. 2, Table 2). The fluxes were significantly higher in 2009, which was probably related to the end of the outburst. In the spectrum that followed, carried out in 2015, the forbidden lines had the same flux as during the outburst.

The H and He permitted lines showed a gradual decrease in the years 2005–2008 (Fig. 2, Table 2) similar to the one observed in photometric observations (Fig. 4). In 2009, when the photometric decline had come to a halt, the permitted emission lines showed an increase in flux similar to the one observed in the case of forbidden lines. Moreover, in 2015, both the permitted and emission lines showed similar fluxes to those found at the end of the photometric decline.

In the case of the [Fe X] 6375 emission line the variability is the most complicated. The behavior of this line is similar to the variability seen for H and He permitted lines. The only difference is that the first two of our spectra show an increase in flux which is succeeded by a gradual decrease. This may be

Table 3. Parameters of the red giant from analysis of the infrared SED of LMC S154.

Parameters	Best value	Probability (%)
T_{eff}	4000	79.76
L	$12\,300 L_{\odot}$	78.29
$\log g$	0	100
Mass	$2 M_{\odot}$	100
C/O	2	43.15
\dot{M}_{dust}	$1.27 \times 10^{-9} M_{\odot} \text{ yr}^{-1}$	35.75
R_{in}	$4.5 R_{\text{star}}$	100
$\tau_{11.3}$	0.2	100

Notes. \dot{M}_{dust} – dust mass-loss rate, R_{in} – inner radius of the dust shell, $\tau_{11.3}$ – optical depth at 11.3 microns.

related to stopping of the WD wind, which lead to a decrease in the density of the material close to the WD, and allowed for emission of forbidden lines in a high-excitation environment.

4. Cool component

The cool component of LMC S154 was classified as a C-rich giant by Muerst et al. (1996). The authors determined its type as C2.2. Nevertheless, thus far the chemical composition of the RG has not been estimated and only the chemical composition of the nebula around the system has been calculated using emission lines (Vogel & Morgan 1994). This gave a consistent overabundance of carbon (C/O = 1.19). Nevertheless, the outburst in the history of the system can pollute the nebula with material from the WD and cause the abundances to misrepresent the giant chemical composition (see e.g., Iłkiewicz et al. 2015). For this reason we attempted to estimate the carbon abundance in the cool component of LMC S154 by fitting a synthetic spectrum to the observations.

In order to obtain an initial guess for the RG parameters we fitted a GRAMS C-rich grid of models of dust shells around red supergiant and AGB stars (Srinivasan et al. 2011) to the infrared spectral energy distribution (SED) of LMC S154. We employed photometry from 2MASS All-Sky Point Source Catalog (Skrutskie et al. 2006), AKARI/IRC Mid-Infrared All-Sky Survey (Ishihara et al. 2010), and the IRAS Catalog of Point Sources (Helou & Walker 1988). Bayesian analysis of data was performed using the virtual observatory SED analyzer (VOSA) service (Bayo et al. 2008). We assumed $E_{B-V} = 0.17$ (Muerst et al. 1996) and a distance to LMC of $d = 49.97$ kpc (Pietrzyński et al. 2013). The caveat is that the models were only for a solar metallicity and in the grid of models there was a highest possible $\log g = 0$. The results of our analysis are presented in Table 3.

We calculated synthetic spectra using the SPECTRUM code (Gray & Corbally 1994) and models from Castelli & Kurucz (2004). During calculations we employed the updated Plez (1998) TiO line list from their website⁴ and solar abundances from Grevesse & Sauval (1998). We assumed LMC metallicity $[M/H] = -0.5$ dex and $\log g = 0$. Our grid of synthetic spectra consisted of models with $T_{\text{eff}} = 3500\text{--}4500$ K and $[C/M] = 0.0\text{--}1.0$ dex. The results of least square fitting of synthetic spectra to the SALT spectrum of LMC S154 are presented in Fig. 7. Using this procedure we derived $T_{\text{eff}} = 4000 \pm 250$ and $[C/M] =$

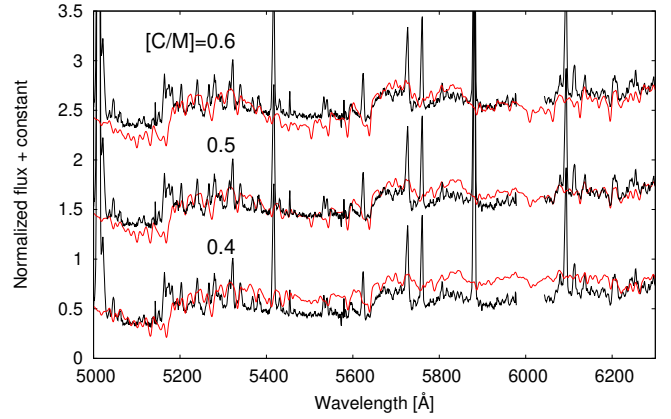


Fig. 7. Fit of synthetic spectra (red lines) to the SALT spectrum of LMC S154 (black lines).

0.50 ± 0.05 dex. Additional uncertainty could be introduced by the presence of a nebular contribution to the continuum, which we did not consider.

After assuming the same oxygen abundance as assumed metallicity from our fit we derive $C/O \approx 1.7$. This value is clearly higher than $C/O = 1.19$ derived by Vogel & Morgan (1994) for the nebula, even taking into account the relatively low accuracy of the Vogel & Morgan (1994) method. This confirms that the nebula has been polluted by the material ejected from the WD during the nova outburst.

5. WD evolution during outburst

During a maximum of both a SyNe and Z-And outburst the WD experiences a “supergiant phase”, where the WD resembles an A–F supergiant. During this phase most of the light is shifted towards optical bands. Therefore, we can estimate a luminosity of the WD during maximum by measuring the brightness of the system in the optical bands, assuming that the bolometric correction $BC \approx 0$. The maximum m_{pg} observed in the archival outburst was ~ 13.1 mag (Fig. 5). Due to gaps in photometric data we assume this is the maximum magnitude during both outbursts. A lower limit of the maximum magnitude of the 1980s outburst is ~ 14 mag. After correcting for a reddening $E(B-V) = 0.17$ mag (Muerst et al. 1996) and using a distance to LMC of 49.97 kpc (Pietrzyński et al. 2013) this method gives a $L_{\text{WD}} \sim 8300\text{--}23\,000 L_{\odot}$ during the outburst maximum.

At the beginning of the nebular phase, the luminosity of the WD has been estimated to be $L_{\text{WD}} = 3000 \pm 1000 L_{\odot}$ in May 1993 (Vogel & Morgan 1994; Muerst et al. 1996) based on UV spectroscopy. Using our data we can estimate WD luminosity with Eq. (8) of Kenyon et al. (1991). Fluxes measured in 2015 (Table 2) after correcting for reddening give $L_{\text{WD}} \sim 4200 L_{\odot}$. Similarly, the O VI 6825 flux from the same spectrum gives $L_{\text{WD}} \sim 4700 L_{\odot}$ using Eq. (8) of Mikolajewska et al. (1997). Both of these estimates have an uncertainty of a factor of two.

While there is no data covering the maximum of the outburst allowing us to estimate WD temperature, Muerst & Nussbaumer (1994) estimated $T_{\text{hot}} = 140 \pm 15$ based on spectra from 1993. Using our data we can estimate the temperature of the WD using a relation proposed by Muerst & Nussbaumer (1994):

$$T_{\text{WD}}(1 \text{ kK}) = \chi_{\text{max}}(\text{eV}), \quad (1)$$

where χ_{max} is the highest observed ionization potential. The highest ionization stage observed in LMC S154 is Fe^{+10} , which gives $T_{\text{WD}} = 291$ kK.

⁴ <http://www.pages-perso-bertrand-plez.univ-montp2.fr/>

Table 4. Parameters of the WD during outburst (see text).

Outburst phase	Year	$L_{\text{WD}} (L_{\odot})$	$T_{\text{WD}} (\text{kK})$
Maximum	1980's	8300–23 000	
Early nebular phase	1993	3000 ± 1000	140 ± 15
Nebular phase	2015	~ 4200	291

Evolution of the WD during outburst is presented in Table 4. During the decline from maximum, the temperature of the WD increased by over a factor two. Such a behavior is expected during decline from classical nova outburst, and was observed for example in the SyN PU Vul (Kato et al. 2012).

6. Symbiotic nova classification

Based on the evolution of the WD parameters during the drop from maximum it is clear that the variability of LMC S154 is due to an outburst. However, a similar low-amplitude outburst could be explained by a Z And-type outburst, and the SyN nature of the system cannot be confirmed by a light curve and WD parameters alone.

We confirm the SyN nature of the object using spectroscopic features detected in the spectrum during nebular phase. LMC S154 shows a rich nebular spectrum, which is not observed in Z And-type stars after outburst. In particular, the [N II] forbidden lines are in strong emission in LMC S154, while in the case of Z And-type outbursts, forbidden lines with such low critical densities are never observed (see e.g., Miszalski et al. 2014 and references therein).

Another strong argument in favor of the classical nova classification is provided by the evolution of the object in X-rays. In LMC S154, X-rays were detected only near the maximum of outburst and have not been detected since then (Remillard et al. 1992). The opposite is expected in the case of Z-And-type outbursts, where the X-ray flux is lowest during outburst and highest during quiescence (Greiner et al. 1997).

7. Conclusions and discussion

While nova outbursts have been suggested for some extragalactic SySts, none have thus far been proven. This is perhaps mainly due to the fact that observations have never been carried out of all of the phases of an outburst in these systems. Most notably, in the case of Sanduleak's star, outburst was suggested on the basis of monotonic fading of the star (Angeloni et al. 2014), but the beginning of the outburst was not observed in the history of the star, nor did the star reach quiescence. Moreover, an outburst was suggested in the case of M31SyS J004322.50+413940.9 (Mikołajewska et al. 2014) but was never demonstrated.

In this work we study the possible evidence for the suggested nova outburst in the history of the extragalactic SySt, LMC S154. We gathered archival observations which confirmed that the variability of the system is due to a classical nova outburst. Results of our monitoring in the years 2005–2015 show that the outburst ended in 2009. This means that the star finally reached quiescence and all phases of an outburst were observed. Abundance of carbon in the photosphere of the RG is significantly higher than the abundance derived for the nebula, which confirms pollution of the circumbinary material by the nova ejecta. The luminosity and temperature changes of the WD are consistent with a nova

outburst. The available evidence proves that LMC S154 is a bona fide SyN.

The archival data strongly suggest that there has been more than one outburst recorded in the history of LMC S154, which would make this system a member of a rare class of SyRNe. This makes this object the first SyRN in MCs and in general the third recurrent nova in the LMC (see e.g., Mróz et al. 2016). While it is possible that LMC S154 showed only one nova outburst with one long maximum or more than one shorter maximum, as in the case of RX Pup (Mikołajewska et al. 1999), the SyRNe classification is supported by the detection of [O III] lines between the two observed maxima, in the 1940s and in the 1980s, and the nondetection in the 1980s. These lines are characteristic of the nebular phase of outburst, and once detected they last until the end of outburst, even if more than one maximum of the outburst is present (see e.g., RX Pup). This means that the maxima detected in the 1940s and the 1980s were associated with two different outbursts, and that each of them was followed by a nebular phase. Also in favor of the SyRN nature of LMC S154 is the discovery of [Fe X] and [Fe XI] coronal lines. These lines are rare in SySts, and in SyNe they are observed only during the SSXS phase of nova outbursts on a massive WD. Another argument in favor of the recurrent nature of LMC S154 is provided by the detection of X-ray radiation in the 1980s. The X-ray radiation from LMC S154 most probably originated in a shock produced by an expanding blast wave, which is expected at the earliest phases of an outburst.

LMC S154 is the first classical nova to be discovered with a C-rich donor. While there have been no theoretical studies of nova outbursts with such a C-rich donor, it is clear that the abundance of carbon in the accreted material will have an influence on the evolution of the outburst. Together with the fact that LMC S154 appears to suffer an outburst of a significantly longer timescale compared to other SyRNe (T CrB, V745 Sco, V3890 Sgr and RS Oph), this makes this object an interesting case for the study of nova outbursts.

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