

FIRST REPORT ON THE NOVA LMCN 2019 07a IN THE LARGE MAGELLANIC CLOUD

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Abstract

This paper presents a summary of the first observational data available for the classical nova LMCN 2019 07a since its discovery by the Brazilian Transient Search (BraTS)¹ team in July 27, 2019. Our comments on the early spectroscopic and photometric results are also presented.

1 - Introduction

The Large Magellanic Cloud (LMC) is generally regarded as an outstanding laboratory to understand the several processes involved in stellar astrophysics. This is due to many reasons, among which:

- The LMC is the third closest galaxy to us, and its distance is precisely known at $50 \text{ kpc} \pm 2.2\%$ (Pietrzynski et al 2013). Its foreground extinction is also well-known and is quite low, with average reddening around $E(B-V) = 0.06$ (Staveley-Smith et al, 2003).
- Besides being in our neighborhood, the LMC is the fourth largest galaxy in the Local Group, with diameter around 4.3 kpc and mass close to 10^{10} solar masses.
- With a diversified stellar content, low metallicity and harboring some 700 open clusters, 270 planetary nebulae, 60 globular clusters, 60 supernovae remnants and X-ray sources, besides the most massive stars known to date (Westerlund, 1996), the LMC is also rich in gas and dust, and it is currently undergoing a dynamic and vigorous star formation activity. Its star formation history includes an initial star formation burst up to some 12 Gyr ago. Then, the star formation rate (SFR) was almost extinguished between 12 and 5 Gyr ago, before reigniting at some 5 Gyr ago. Since then, there would have been SFR peaks at 2 Gyr, 500 Myr, 100 Myr and 12 Myr (Harris and Zaritsky, 2009).

As we will see, many of those factors support the development of a high classical novae rate per unit mass in the LMC. Novae discoveries in the LMC are so a key target for the BraTS team.

2 - Novae rates in the Galaxy, LMC and other galaxies

In the Milky Way Galaxy, the *average* overall novae rate is currently estimated as some 50 yr^{-1} (Shafter, 2017). However, what is *actually discovered* is much less than that. This is due to the high gas and dust content in the Galactic disk regions, having as a consequence a high interstellar extinction. Even in recent years (2008-2018), the *actual* Galactic novae discovery rate has reached only some 10 yr^{-1} (<https://asd.gsfc.nasa.gov/Koji.Mukai/novae/novae.html>). A full list of all 407 novae discovered in the Milky Way Galaxy between 1612 and 2010 may be found in http://www.cbat.eps.harvard.edu/nova_list.html.

¹ Members of the BraTS team (alphabetical order of first names): Carlos Colesanti, Cristóvão Jacques, Eduardo Pimentel, Israel Mussi, João Ribeiro, Leonardo Amaral, Marcelo Domingues, Paulo Holvorcem, Tasso Napoleão.

For the Andromeda galaxy (M31), which has roughly the same mass/luminosity and Hubble morphological class as the Milky Way, the *average* overall novae rates are also comparable to ours: 65 yr^{-1} (Darnley et al, 2006). It might be worth to mention that both in M31 and in the Galaxy, novae usually occur in the disk and in the bulge, being most frequent in the latter. However, the *actual number* of novae discoveries in M31 is substantially higher than in the Milky Way, currently reaching some 30 - 40 yr^{-1} . This may be due to the several M31 novae search programs which took place on a routine basis over the last few decades, besides the relatively low foreground reddening toward the Andromeda galaxy. All M31 novae discovered since 1909 may be found in http://www.mpe.mpg.de/~m31novae/opt/m31/M31_table.html.

On the other hand, since the LMC is about one-hundredth times less massive than either the Milky Way or M31, it would be expected that its overall novae rate should be much lower. That is true in absolute terms: some recent estimates of the novae rate in the LMC are $2.5 \pm 0.5 \text{ yr}^{-1}$ (Della Valle et al 1994) or $2.4 \pm 0.8 \text{ yr}^{-1}$ (Mróz et al, 2016). Here also the *actual* number of novae discoveries is lower than the estimated values. From 1926 to 2019 a total of 55 novae were found in the LMC, which means an average of only 0.6 yr^{-1} . Over the past few years (2008 to 2018), the automated searches have helped to increase that figure to slightly over one nova per year (http://www.mpe.mpg.de/~m31novae/opt/lmc/LMC_table.html). Most of them have been found in the central bar region.

Obviously, there is a strong correlation between the mass/luminosity of a galaxy and its novae rate, and possibly also its Hubble type (Matteucci et al, 2003; Della Valle et al, 1994). However, a direct comparison of novae rates of galaxies with different masses/luminosities and Hubble types is possible by introducing a parameter known as LSNR (Luminosity-specific novae rates). The LSNR employs a galaxy's integrated K-band luminosity as a proxy for the total stellar mass. When we adopt that parameter, the LMC becomes the highest *specific novae rate* galaxy (or rate per unit mass, or K luminosity) among several galaxies in which novae have been discovered. This may be related to the recent LMC's star formation history.

3- Discovery

The nova LMCN 2019-07a was found by the Brazilian Transient Search team (BraTS) in six sky patrol images taken at dawn on July 27, 2019. The BraTS nova search is performed with a Canon 6D camera plus a telephoto lens (200mm, f/1.8) located within the SONEAR Observatory, in the town of Oliveira, MG, Brazil. Images are routinely processed with the software SkySift, developed by Paulo Holvorcem², one of BraTS members. All potential detections selected by the software are then checked by one of the team members either online or early in the morning.

The first of the discovery images was taken on 2019 July 27.34967 UTC (about 05h23m local time). The suspect object was located at the central bar of the LMC (at R.A. 05h29m36.66s, Declination $-70^{\circ}09'56.6''$). Its magnitude was 12.6 at that moment; its height over the horizon was approximately 30° at azimuth 160° . The Sun would rise at 06h32m local time. A few hours later, the six images were checked and discussed among the team members. Previous images, taken just two days before, showed that nothing was visible at that position. Both the object's astrometry and absolute magnitude (calculated taking into consideration LMC's actual distance and foreground reddening) were strong indicators that it could be a nova. Figure #1 shows three of the discovery images on the SkySift panel.

² Information about the SkySift software is available at <http://sites.mpc.com.br/holvorcem/>.

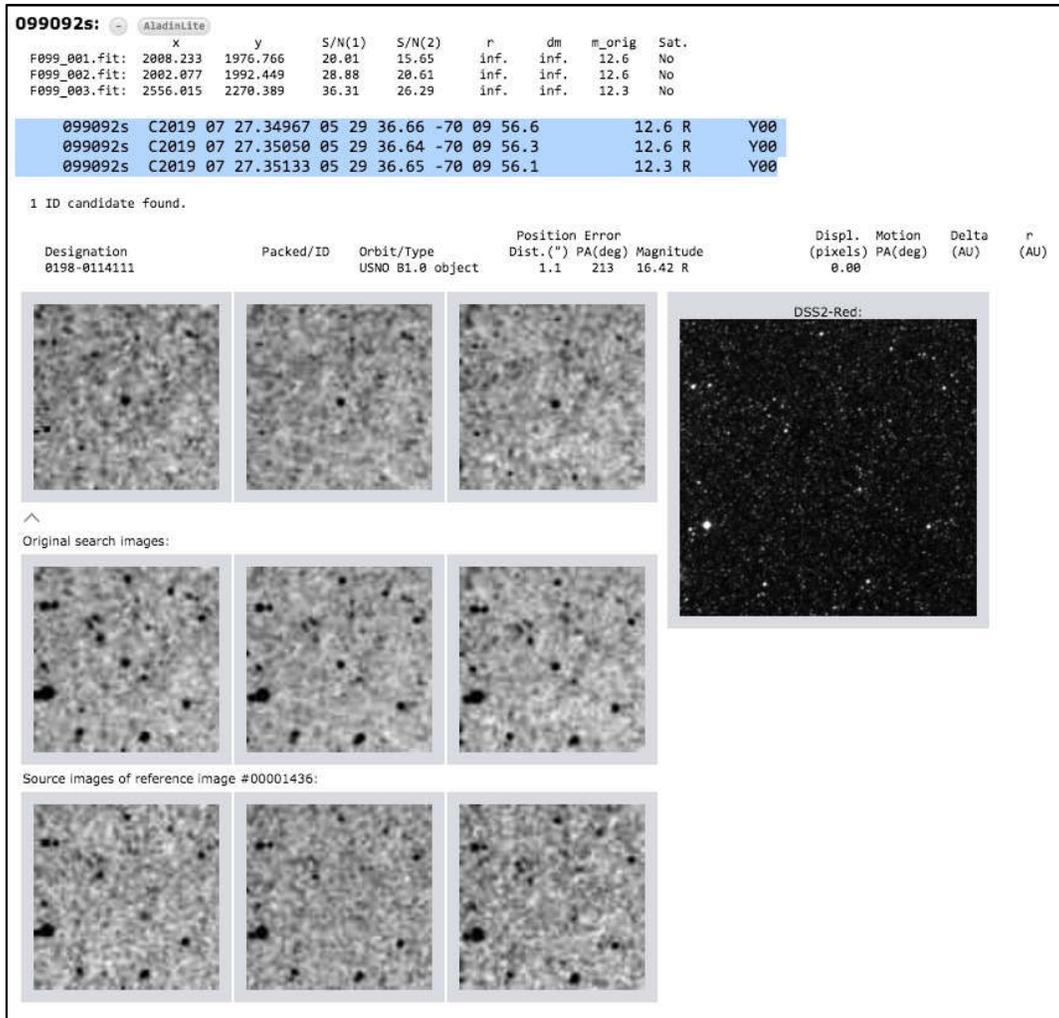


Figure #1: Discovery images of nova LMCN 2019-07a (SkySift software). The three search images in the central line were taken at the moments marked in blue, above. The DSS2 image at right helps to confirm the identification. Source: BraTS.

A communication (seen below) was then sent to CBAT (Central Bureau for Astronomical Telegrams, of the International Astronomical Union), through the “Transient Objects Confirmation Page” (TOCP), at <http://www.cbat.eps.harvard.edu/unconf/tocp.html>. The object received the provisional denomination of de TCP J05293666-7009566³.

TCP J05293666-7009566

2019 07 27.3496

Discovered by C. Jacques, L. Amaral, C. Colesanti, E. Pimentel, I. Mussi, J. Ribeiro, M. Domingues, P. Holvorcem, T. Napoleao on behalf of the Brazilian Transient Search - BraTS - at SONEAR Observatory, Oliveira, Brazil with six frames with 60 seconds exposure using a telephoto 200m f/1.8 + Canon 6D camera with magnitude 12.6 under limiting mag = 15.5. Nothing is visible at this location on the previous frame (limit mag = 15.5) taken on 2019 July 25.3618 UT. Possible Nova in LMC.

³ The definitive name of the nova (LMCN 2019-07a) would be given one month later.

The position of the nova in the Large Magellanic Cloud can be seen in Figure #2. It clearly belongs to LMC's central bar, where most of the recent novae have been found.

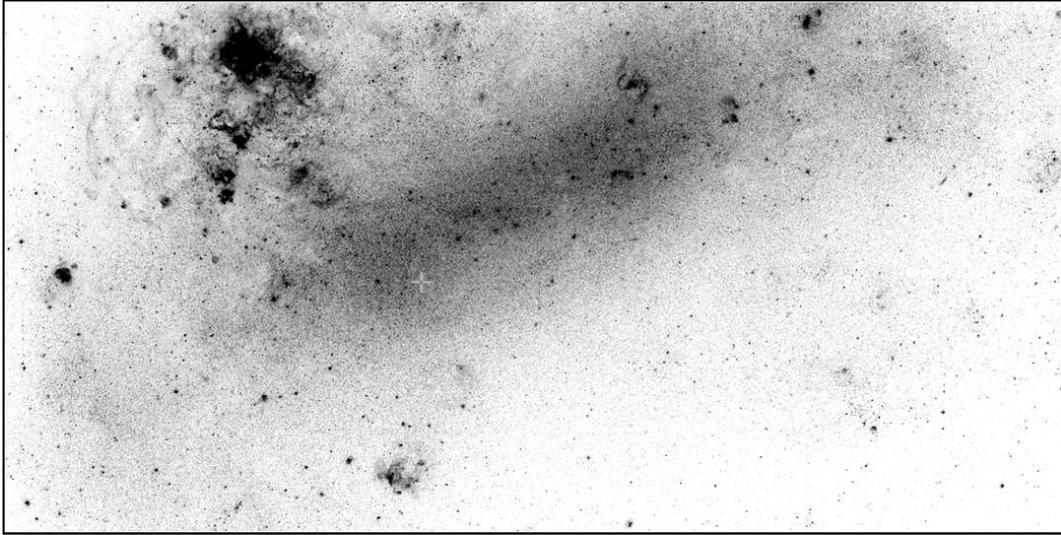


Figure #2: LMCN 2019 07a position in the central bar of the LMC. Image source: DSS2.

4 - Spectroscopy

In order to confirm the nature of TCP J05293666-7009566 as a nova, a spectrum was needed. This became available two days after discovery (Aydi et al. ATEL 12963). Three spectra were made by a team of MSU (*Michigan State University*) with the Goodman spectrograph at the 4.1m SOAR telescope, in Cerro Pachón, Chile. One of them is presented in Figure #3. Several features there are typical of a FeII nova at the “pre-maximum” (fireball) stage: strong Balmer (H α) lines, many of them showing P-Cygni profiles; and thin lines of FeII, NaI and OI. According to the MSU team, the FWZI (full width at zero intensity) was measured as approximately 1250 km/s (absorption + emission), which suggests a moderately fast expansion, which is also a characteristic of FeII novae.

As a reminder, since the early 1990s it is known that novae spectra are split into two major groups: the “FeII novae”, which typically present strong Balmer lines, thin FeII emission lines, well-defined P-Cygni profiles, and moderate to fast gas expansion speeds; and the “He/N novae”, with strong and broad lines of helium and nitrogen, very high expansion velocities (in excess of 2500 km/s) and fast spectral evolution (Williams, 1992). Further research has demonstrated that the He/N lines originate in the white dwarf ejecta, while the FeII lines are consistent with their formation in a large circumbinary gaseous envelope whose origin is the companion star (Williams 2012).

The analysis of all available novae spectra throughout the years has shown that, for galaxies such as M31 and the Milky Way, the ratio between He/N and FeII novae is roughly 20% for the former and 80% for the latter. However, when the LMC is under study, statistics are quite different: 50% of the novae show He/N spectra, while the other 50% are of the FeII type. Also, and as a general rule, LMC novae are in average faster than in either M31 or the Milky Way. One likely explanation for those facts is related to the prevailing stellar populations among those galaxies (Shafter, 2013): most of the LMC novae seem to originate in the intermediate

and young population (1-3 Gyr in average), while most of the novae in M31 and in the Galaxy come from regions closer to the bulge, where the average population age is near to 12 Gyr. Stellar population models (Yungelson et al., 1997) suggest that the younger population produces progenitor binaries with higher average white dwarf masses. Novae from massive white dwarfs tend to be faster than those with lower-mass primaries. And because high-mass white dwarfs need to accrete a smaller amount of gas to ignite a nova eruption, specific nova rates (as per the LNSR) would be enhanced (Mróz et al., 2017). This is exactly the kind of effect we can see in the LMC.

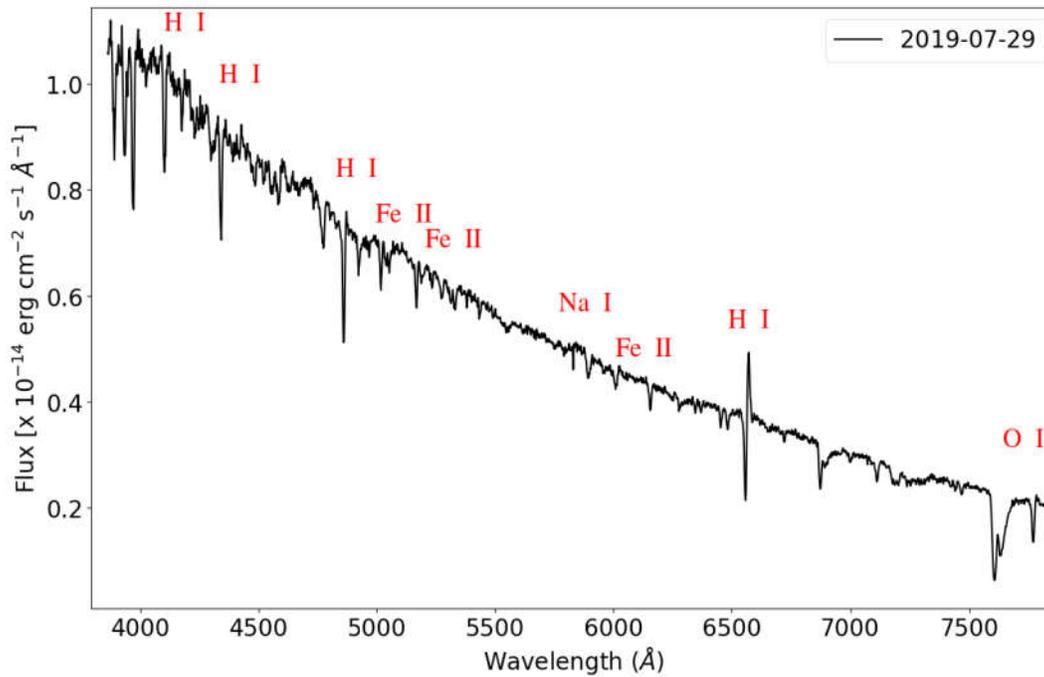


Figure #3: Spectrum of TCP J05293666-7009566 taken one day before maximum by MSU / SOAR team (Aydi et al., ATEL 12963).

5 – Photometry, light curve and the MMRD

Upon discovery (July 27.34967 UTC or, expressed in Julian Dates, JD 2458691.84931) the nova was shining with magnitude 12.6. For some three days, its brightness kept increasing and was followed by several observers in the Southern Hemisphere. The most complete and reliable follow-up has been performed by AAVSO (American Association of Variable Stars Observers). At the time this report is being written (two months after discovery), AAVSO members had already made 367 magnitude estimates in the Johnson UBVRI photometric standard. The following considerations and calculations will be based primarily on AAVSO data. We would like to acknowledge and thank AAVSO and its observers for making available openly and freely their outstanding quality data.

We will start by finding the speed class of the nova. This classification was originally developed by McLaughlin (1939, 1945) and Payne-Gaposchkin (1957). Essentially, it expresses the rate of the brightness decay of the nova after its peak luminosity, and is usually measured by two parameters which can be extracted from the light curve: t_2 and t_3 (time interval in days to decay respectively by two and three magnitudes from maximum). Let us consider the AAVSO (V) light curve, as seen in Figure #4.

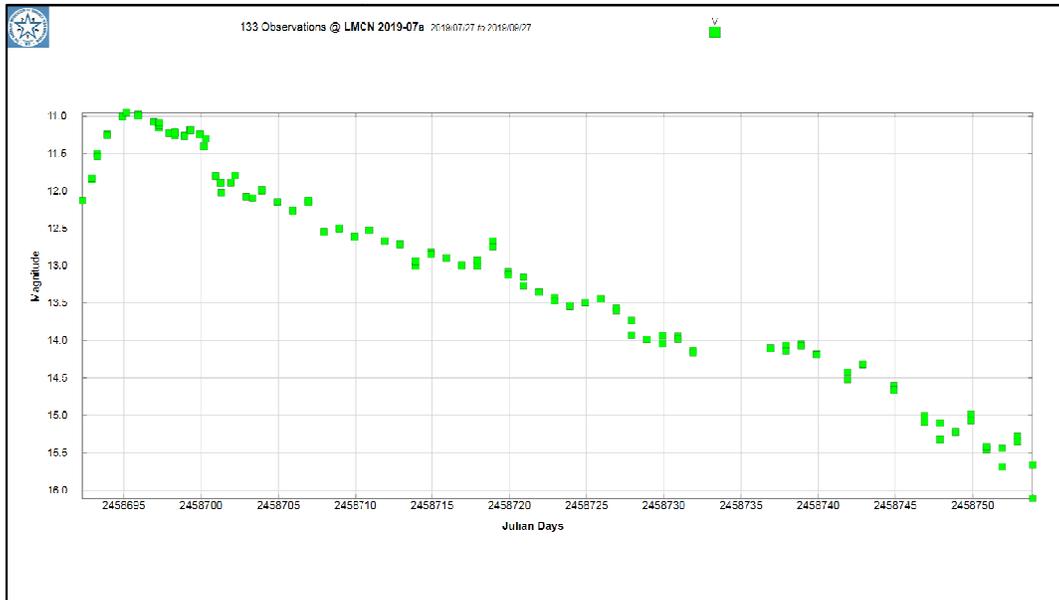


Figure #4: AAVSO (V) light curve for nova LMCN 2019-07a from July 27, 2019 to September 27, 2019. Source: AAVSO.

From the light curve (and using AAVSO software VSTAR for all measures and calculations), we find the maximum brightness ($V = 10.95$) at $JD = 2458695.19$. With that value we can easily find t_2 and t_3 :

For t_2 , we find the JD corresponding to magnitude 12.95, which was $JD = 2458715.92$. It turns out that $t_2 = 2458715.92 - 2458695.19 = 20.73$ days (or approximately 21 days).

For t_3 , we find the day the magnitude reached 13.95, which was $JD = 2458729.91$. Now it turns out that $t_3 = 2458729.91 - 2458695.19 = 34.71$ days (or approximately 35 days).

The most widely used classification is that introduced by Cecilia Payne-Gaposchkin (1957). Her definition of speed classes is based on t_2 and lists five classes: very fast novae ($t_2 < 10$ days), fast novae (11-25 days), moderately fast novae (26-80 days), slow novae (81-150 days) and very slow novae (151-250 days). By her criteria, our nova LMCN 2019-07a belongs to the fast novae group (*but not far from the moderately fast class*). This behavior, as we will see, is quite common in the LMC.

The next step will be to calculate the absolute magnitude and luminosity of LMCN 2019-07a. We will use an empirical relation known as “MMRD” (“maximum-magnitude-rate-of-decline”), originally proposed by McLaughlin (1945), which takes into account the fact that for all novae there is a well-defined correlation between its luminosity at maximum light and its rate of decline. Since then, there have been numerous characterizations of the MMRD relation for Galactic and extragalactic novae. All of them have been quite useful for calculating the absolute magnitude of each nova and, from there, its distance. For the purpose of this work, we will calculate (on a comparative basis) the absolute visual magnitude M_v through some of the most widely used forms of the MMRD relation from the available literature:

Relations based on t_2 :

1. $M_v = -7.92 - 0.81 \arctan [(1.32 - \log t_2)/0.23]$ (Della Valle; Livio, 1995)
2. $M_v = -11.32 + 2.55 \log t_2$ (Downes; Duerbeck, 2000)
3. $M_v = -8.02 - 1.23 \arctan [(1.32 - \log t_2)/0.23]$ (Downes; Duerbeck, 2000)
4. $M_v = -9.60 + 0.28 \log t_2 + 0.70(\log t_2)^2$ (Liller; Shida, 2004)

Relations based on t_3 :

1. $M_0 = -11.8 + 2.5 \log t_3$ (Schmidt-Kaler, 1957)
2. $M_v = -11.99 + 2.54 \log t_3$ (Downes; Duerbeck, 2000)

From the values of t_2 e t_3 calculated above, we can estimate M_v :

MMRD relations based on t_2 :

Relation #	References	M_v
1	Della Valle; Livio, 1995	-7.93
2	Downes; Duerbeck, 2000	-7.96
3	Downes; Duerbeck, 2000	-8.03
4	Liller; Shida, 2004	-8.02

MMRD relations based on t_3 :

Relation #	References	M_v
1	Schmidt-Kaler, 1957	-7.95
2	Downes; Duerbeck, 2000	-8.07

In the case of nova LMCN 2019-07a, there is an alternative method of calculating the absolute visual magnitude M_v . Since the nova resides in the Large Magellanic Cloud, whose distance and reddening are well-known, we can simply use the distance modulus equation. Taking into account the distance given by Pietrzynski et al. 2013 (49.97 kpc \pm 2.2%), plus the total reddening (foreground + extragalactic) of 0.12 measured by Imara and Blitz (2007), and remembering that the maximum apparent magnitude was 10.95, we can write:

$$m_v - M_v = 5 \log d - 5 + A_v$$

$$10.95 - M_v = 5 \log 49970 - 5 + 3.1 \times 0.12$$

$$M_v = -7.91 \pm 0.05$$

This result is quite consistent with the values obtained through the MMRD process, and appears also to be typical of the population of novae in the Large Magellanic Cloud: a recent study by Shafter (2013), based on photometric and spectroscopic data available about all LMC novae since 1926 to the end of 2012 has shown that their average M_v was 8.1.

The absolute visual magnitude of roughly -7.9 found for LMCN 2019-07a can also be converted in luminosity (in solar units) as follows:

$$M_\odot - M_{\text{nova}} = 2.5 \log (L_{\text{nova}} / L_\odot)$$

$$4.8 + 7.9 = 2.5 (L_{\text{nova}} / L_\odot)$$

$$(L_{\text{nova}} / L_\odot) = 120\,226$$

Roughly speaking, the nova had 120 thousand times the Sun's luminosity at its maximum.

6 - Conclusions:

Although only two months have passed since after LMCN 2019-07a discovery, we believe some preliminary conclusions can already be made as seen below. Over the next few months, we expect to have additional photometric and (hopefully) spectral data available; this will enable further analysis.

- BraTS discovery image was taken at JD 2458691.84931. Our previous image of the region was made at JD 2458689.86181; nothing was visible up to the limiting magnitude (15.5). Data from ASAS-SN Sky Patrol (Figure #5) show that there was nothing visible up to their limiting magnitude (16) at JD 2458688.94324. All of that suggests that the nova was found while it was rising to maximum, which took place two days later; and that the explosion probably occurred 2 – 3 days before discovery. At this point in time, however, we are unable to identify the nova's progenitor star.

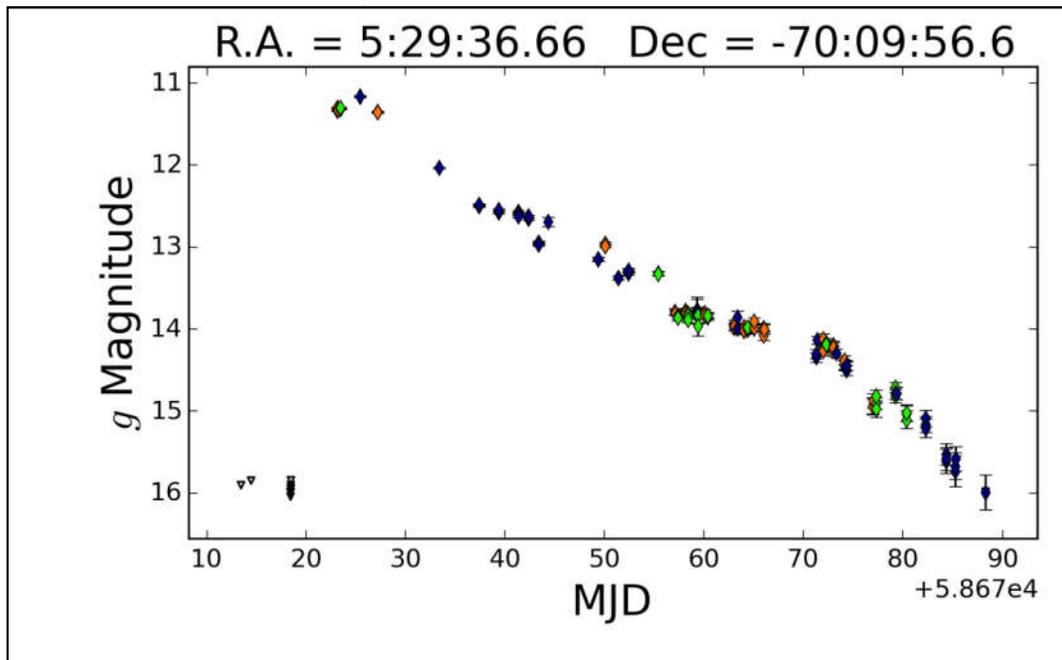


Figure #5: Light curve of LMCN 2019-07a from ASAS-SN Sky Patrol website.

- The nova spectra obtained by the MSU/SOAR team appear to be compatible with a FeII nova in the “fireball” phase before visual maximum (which, as per AAVSO light curve, would occur one day after the spectra was taken). Both the expansion velocities from the spectra and the absolute magnitude as measured by the MMRD results indicate this is a moderately fast nova. Let us see below how this compares with other LMC novae.
- The nova rate of decline after maximum may be calculated either through $(2/t_2)$, or through $(3/t_3)$, or even through the average between those two values whenever both are available (Shafter, 2013). The latter is our case, and so we can estimate that the rate of decline of LMCN 2019-07a was approximately $v = 0.09$ magnitude/day. Now let us consider Figure #6, from Shafter et al (2014), which presents the MMRD relation for a sample of 30 novae found in the LMC. The “He/N novae” (faster, brighter and with higher-mass white dwarfs) are seen as squares in the diagram. On the other hand, the

“Fell novae” (slower and less luminous than the previous ones) are seen as circles. The crosses represent the novae whose spectroscopic classes were not available. The red triangle represents the position of LMCN 2019-07a as per our calculations. We believe from the diagram that it is quite compatible with a typical Fell nova, and also that this reinforces the spectroscopy results as seen before. The dashed line is the best fit MMRD relation for this LMC novae sample (Shafter et al., 2014):

$$M_v = -(1.52 \pm 0.24) \log_{10} v - 6.27 \pm 0.32$$

For LMCN 2019-07a this equation provides $M_v = 7.7 \pm 0.5$, which is also compatible with our previous results.

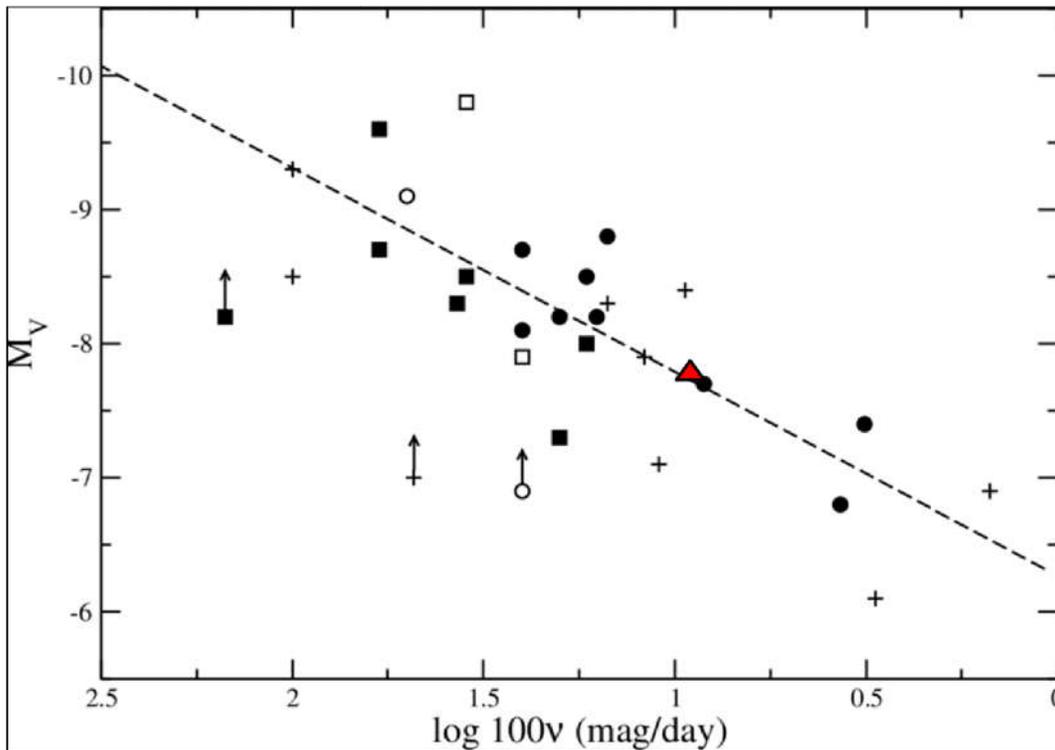


Figure #6 - MMRD for a sample of 30 novae in the LMC (Diagram from Shafter et al., 2014).

- Finally, let us estimate the mass of the nova’s white dwarf (WD) component. As we said before (and according to Shafter, 2013 and Mróz et al., 2016), we know that the brightest novae (or those which show shortest t_2 ou t_3) are also those which have the highest-mass WDs. As we have just seen, LMCN 2019-07a (although classified as a “fast nova” as per the classical criteria of Payne-Gaposchkin, 1957), obviously *does not belong* to the fastest novae subgroup within the LMC population (see Figure #6). Perhaps it would be more adequate call it a “moderately fast” nova. As a consequence, we should expect that his white dwarf component is not a high-mass one (and clearly far from the Schenberg-Chandrasekhar limit).
- We can calculate the white dwarf mass using an analytical expression developed by Mario Livio, which is a correlation between the absolute B magnitude at maximum with the white dwarf mass in solar units (Livio, 1992):

$$M_B = - 8.3 - 10.0 \log (M_{\text{dwarf}}/M_{\odot})$$

In order to get an estimate of the M_B value, we will again need the help of the AAVSO International Database already quoted. From AAVSO data, we can get the value of the *apparent* magnitude at maximum ($m_B = 11.3$). From m_B we can now calculate M_B by using the distance modulus equation as seen below (recalling that the extinction here is A_B , which is equivalent to $1.324 A_V$):

$$m_B - M_B = 5 \log d - 5 + A_B$$

$$11.3 - M_B = 5 \log (5 \times 10^4) - 5 + 0.49$$

The result for the absolute magnitude in B is $M_B = -7.65$. Taking this value to Livio (1992) correlation, we get the white dwarf mass in solar units:

$$(M_{\text{dwarf}}/M_{\odot}) = 0.86$$

Or, approximately, we may say that the white dwarf has mass around 0.9 solar masses. We searched for comparable results from other novae WDs in the available literature. In Hachisu; Kato (2006, 2007), a new brightness decline law for classical novae is presented by the authors; although no exact counterpart to LMCN 2019-07a is available in their papers, interpolations with some reasonably close examples given by them (V1668 Cyg, V1974 Cyg) indicate a WD mass in the range of 0.95 solar masses – which seems not too far from the value obtained through the use of Livio (1992) correlation.

References

AAVSO (American Association of Variable Stars Observers). Website. Disponível em: <https://www.aavso.org/>.

Aydi, E. et al., Spectroscopic classification of TCP J05293666-7009566 as a likely classical nova in the LMC, ATEL 12963. Available in: <http://www.astronomerstelegam.org/?read=12963>.

Darnley, M. J. et al., Classical novae from the POINT-AGAPE microlensing survey of M31, *Monthly Notices of the Royal Astronomical Society* 369, 257–271, 2006.

Della Valle, M. et al., The nova rate in galaxies of different Hubble types, *Astronomy and Astrophysics* 287, 403, 1994.

Della Valle, M.; Livio, M., The calibration of novae as distance indicators, *Astrophysical Journal* 452:704, 1995.

Downes, R.; Duerbeck, H., Optical imaging of nova shells and the MMRD relationship, *Astronomical Journal* 120 :2007, 2000.

Hachisu, I.; Kato, M., A universal decline law of classical novae, *Astrophysical Journal Supplement Series*, 167:59, 2006.

Hachisu, I.; Kato, M., A universal decline law of classical novae II. *Astrophysical Journal*, 662:552, 2007.

- Harris, J.; Zaritsky, D., The star formation history of the Large Magellanic Cloud, *Astronomical Journal*, 138, 1243–1260, 2009.
- Imara, N.; Blitz, L., Extinction in the Large Magellanic Cloud, *Astrophysical Journal* 662:969, 2007.
- Liller, W.; Shida, R., Magellanic Clouds novae and the peak magnitude vs rate-of-decline relationship, *ASP conference series*, vol 310, 2004.
- Livio, M., Classical novae and the extragalactic distance scale, *Astrophysical Journal*, 393:516, 1992.
- Matteucci, F. et al., 2003, Modelling the nova rate in galaxies, *Astronomy and Astrophysics* 405, 23–30, 2003.
- McLaughlin, D.B., The light curves of novae. *Popular Astronomy*, 47, 410, 1939.
- McLaughlin, D.B., The relation between light-curves and luminosities of novae. *Publications of the Astronomical Society of the Pacific*, 57, 335, 1945.
- Mróz, P. et al., OGLE Atlas of classical novae II – Magellanic Clouds, *Astrophysical Journal Supplement Series*, 222:9, 2016.
- Payne-Gaposchkin, C. *The galactic novae*. New York: Dover Publications, 1957.
- Pietrzynski, G. et al., An eclipsing binary distance to the Large Magellanic Cloud accurate to 2 per cent, *Nature* vol 495, 76–79, 2013.
- Schmidt-Kaler, Th. Die Lichtkurven-Leuchtkraft-Beziehung Neuer Sterne. *Zeitschrift für Astrophysik*, 41, 182, 1957.
- Shafter, A. W., The Galactic nova rate, in Hernanz, José (eds), *Classical Novae Explosions*, AIP, 2002.
- Shafter, A. W. , Photometric and spectroscopic properties of novae in the Large Magellanic Cloud, *Astronomical Journal* 145:117 (11pp), 2013.
- Shafter, A. W. et al., Extragalactic nova populations, *ASP Conference Series*, Vol. 490, 2014.
- Shafter, A. W., The Galactic nova rate revisited, *Astrophysical Journal*, 834:196, 2017.
- Staveley-Smith, L., et al., A new look at the large-scale H I structure of the Large Magellanic Cloud, *Monthly Notices of the Royal Astronomical Society* 339, 87–104, 2003.
- Warner, B. Properties of novae: an overview. In: Bode, M.; Evans, A. (eds), *Classical Novae*, Wiley and Sons, 1989.
- Westerlund, B.E. *The Magellanic Clouds*. Cambridge: Cambridge University Press, 1996.
- Williams, R. The formation of novae spectra, *Astronomical Journal*, Volume 104, Number 2, 1992.

Williams, R. Origin of the "He/N" and "Fe II" spectral classes of novae, *Astronomical Journal*, Volume 144, # 4, 2012.

Yungelson, L., et al., On the rate of novae in galaxies of different types, *Astrophysical Journal* 481:127, 1997.

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