M81 extragalactic nova explosions

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(Dated: June 4, 2021)

Using data from the Joan Oró telescope (located in Montsec, Catalonia) and the reference catalogue from Max Planck Institute, we will observe the evolution of different novae in the M81 galaxy. This article explains the data analysis that has been performed and comments the obtained results.

I. INTRODUCTION

In a binary system formed by a white dwarf and a star that has left the principal sequence, a matter transfer is produced from this last star due to its transformation into a red giant. An outburst is produced, caused by explosive hydrogen burning on the accreted envelope of the white dwarf in a cataclysmic variable [1]. The outermost layers of the red giant are expanded and ejected, and are gravitationally captured by the white dwarf (this phenomenon is called accretion). The accumulated material, composed mostly of hydrogen and helium, is compacted at the surface of the white dwarf due to the intense gravitational field. The temperature of the material increases progressively as more and more material builds up at the surface of the star until it eventually gets to a critical temperature and the nuclear fusion starts. This explosion transforms large quantities of hydrogen and helium into heavier elements. It causes the brightness of the star to increase to maximum luminosities up to 10^5 L_{sun}. Nonetheless, a fraction of the hot envelope can remain in steady hydrogen burning on the surface of the white dwarf [2] [3], powering a supersoft X-ray source (SSS) that can be observed directly once the ejected envelope becomes optically thin to X-rays. The duration of the SSS phase is related to the white dwarf mass and the chemical abundances of the envelope, whereas the time needed by the envelope to become transparent and let the SSS be observable is related to the ejected mass.

Our position within the Milky Way introduces large biases in Galactic population studies. Therefore investigating novae in other galaxies not only gives a better representation of the overall nova population of those galaxies but also allows us to study how the properties of a nova population vary with the Hubble type of a galaxy.

For example, by studying novae in the Local Group (LMC, M31 and M33), it has been shown that novae in later-type galaxies appear to be faster fading and more likely to belong to the He/N spectroscopic class [4].

The Galaxy M81, with a nova rate of 33 ± 13 per year and at the distance of only 3.6 Mpc, is the obvious candidate for the first detailed multi-wavelength study of novae beyond the Local Group. Its comparatively early Hubble-type (SAab) also allows us to study novae in a different environment than can be found in the Local Group. Its orientation is almost face-on, which makes it a favourable target to distinguish between bulge and disk novae. To date, 240 nova candidates have been discovered in M81, the first one being observed on plates taken in 1950 [5].

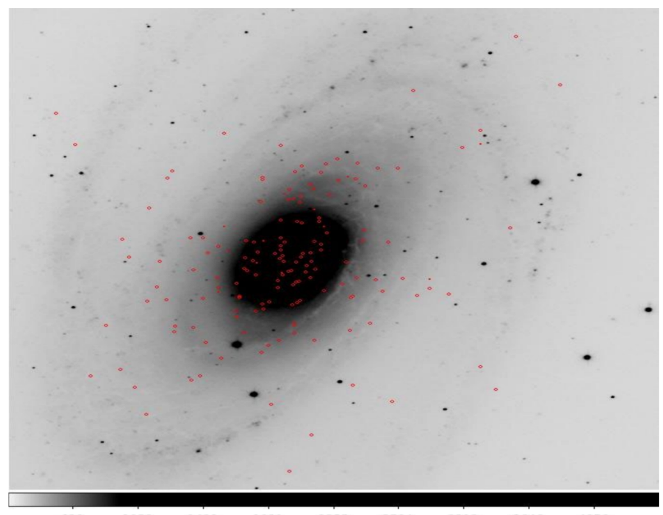


FIG. 1. M81 image obtained with TJO, with a total of 3200 seconds of exposure, in R filter, Red circles indicate the locations of all novae discovered in M81 since from 2000 to 2019.

We will treat the M81 galaxy, also known as Bode's galaxy. It is a spiral galaxy relatively close to Earth (12 milion light years), very attractive for the astronomers for its large size and activity. It is located in the constellation of Ursa Major, and its coordinates are right ascension of 09h 55m 33.2 s and declination +69º 3' 55".

The observational data has been obtained from Joan Oró Telescope (TJO), of the Observatori Astronòmic del Montsec (OAdM). It is the largest telescope in Catalonia (0.8 m). The TJO is equiped with the LAIA instrument, which is the optical imager of TJO. The field of view at TJO without vignetting is 30 arcmin. The CCD camera has a pixel size of 15 x 15 μm (0.4 x 0.4 arcsec). The observations have been done using the red (R) filter of the Johnson-Morgan standardized photometric system. Novae emit large amount of light in the Hα range of the spectrum, which the R filter covers. This filter is used to detect novae since standard stars do not emit with such intensities in the Hα line.

After this introduction, now we can start explaining what we have done in this project to clear, treat and analyze the given data.

II. DATA

As we have commented, the data we will treat come from observations of the galaxy M81. We have used the catalogue of Max Planck für extraterrestrische Physik as a reference, which contains the registry of M81 detected novae since 1950 until nowadays: `https://www.mpe.mpg.de/~m31novae/opt/m81/`. It is a catalogue of novae with their correspondent position and discovery date.

This catalogue was the first step in our project: firstly, we had to understand the magnitudes and units used in it. In astronomy, there are coordinates similar to latitude and longitude, but they are called declination and right ascension. Right ascension (α) is the angular distance of a particular point measured eastward along the celestial equator and it is usually measured in degrees, minutes and seconds. The declination (δ) is measured north or south of the celestial equator along the hour circle passing through the point to measure. It is measured between +90º i -90º. Another essential magnitude is the magnitude of observation (similar to the intensity). It can provide information of what process is the the nova following. This magnitude goes in the inverse of usual: the most intense observations have a magnitude of approximately 18 and the most weak ones a magnitude over 22. Finally, an important magnitude is what is called modified Julian date (MJD). The Julian date is the continuous count of days since the beginning of the Julian period, and it is often used in astronomy and software to better treat the dates. In our work, we will use modified Julian date, that subtracts 2400000.5 to the Julian date to work with smaller numbers.

In order to treat all the data, we decided to use `Python` programming language, as it is very complete and has a lot of libraries that ease the work with files, its treatment and the creation of plots. To better treat this data, we created a first program, called `max_planck_DB_to_csv.py`, where we transferred the magnitudes we wanted from the previous database to `.csv` format, easier to treat later on. Also, in this script we converted the right ascension and declination to degrees, to facilitate the comparison with the observations.

Moreover, we were given two data folders, one with files `.reg` and the other one with files `.log`, with photometric data from 22 March 2016 to 10 December 2018 taken from the Montsec telescope. The former ones are files with a format ready to represent the observations in a plot or image. In this way, we had information, separated by days with the coordinates of every source that had been detected and its corresponding magnitude. For each day of observation we also had a file with the observations filtered to select only the ones that could correspond to novae. On the other hand, the `.log` files (also one for each day of observation) give a summary of the performed observations, uncertainties, date and time of observation, filter,...

In order to better compare the observation files with the reference table, we followed a similar procedure to the previous one: we wrote an script that converted the `.reg` files to `.csv` files, creating the folder `REG_modified`.

III. NOVAE DETECTION ALGORITHM

In order to identify novae among the stars detected in our Montsec data, we compared the coordinates (declination and right ascension) of the sources detected in the observations (`.reg` files) with the ones in the Max Planck catalogue. Our approach is to compare the distance between the observed and the catalogued positions with a certain threshold. If their distance is smaller than this threshold value, we have a coincidence, otherwise we discard the observation.

Our first approach was to compare both declination and right ascension differences to a constant tolerance, that is:

$$|\alpha_{db} - \alpha_{obs}| < \text{tol and } |\delta_{db} - \delta_{obs}| < \text{tol} \tag{1}$$

We took $tol = 10^{-3}$ deg and it worked quite good. It was able to filter out most of the non-novae stars. However it had some obvious drawbacks and could be easily improved. First of all, we were considering a square of side 2·tol around the database coordinated of the star, but it makes more sense to compare the actual distance. Moreover, each observation has its own error in α and δ and we are not considering it. Our final algorithm considers an ellipse with semi-axis depending on the particular error for α and δ of that day.

$$\frac{(\alpha_{db} - \alpha_{obs})^2}{(8\sigma_\alpha)^2} + \frac{(\delta_{db} - \delta_{obs})^2}{(8\sigma_\delta)^2} < 1 \tag{2}$$

Since the fraction of the sky that the M81 galaxy occupies is small, we approximate its coordinates (α and δ, which are in the end spherical coordinates) as cartesian coordinates.

With this algorithm, we still get some anomalous results, but they are few compared to the correct ones.

Now what we had was a folder with one file for each day of observation containing all the candidates to nova observed that day.

IV. FINAL LIGHT-CURVE SYNTHESIS

As we have mentioned, until this step we work with the observations separated by date. The goal of the project is to follow the evolution of different novae in the M81 galaxy and, to do so, it is much better to classify the observations by nova, not by date. This was the following step of the project.

We created a script, called `results.py` which, searching by the name of the nova, travels through the folder of candidates and creates a file for each nova containing all the observations of it (including the date of discovery from the Max Plank catalogue too).

After that, the only step left is to plot the results. To do it, we created a script, called `plots.py`. To plot the results, we took the files generated by `results.py` and generate a `.png` file for each nova.

As it can be seen in figure 4, we have plotted the observations made by the Montsec telescope, the discovery observation, taken from Max Planck catalogue and for each day in the range of the observations where the nova has not been detected, an arrow in the minimum magnitude observed that day. This provides and upper limit for the magnitude of the nova if it has not been detected that particular day. It is possible that that specific day the sky was not very clear and thus very faint magnitudes could not be observed. Also in the same figure, fore each observation, an estimation of the error is plotted. With that, we obtain the range of possible values of the magnitude.

In the annexed material, a scheme of all the steps and scripts and their organization is shown.

V. RESULTS

Now we can comment the results of our project. We have collected 157 observations of possible novae. However, as we have commented, some of them have to be discarded. Some of the stars were discovered around 1950, according to the initial database and, as the observations of Montsec telescope we work with start in 2016, the coincidences in coordinates with that novae are accidents.

With that discarded observations, we end up with 29 observations of 14 different novae. In figure 2 we can see a distribution of this stars by number of observations. As we can see, most of them contain only one observation (apart from the discovery date) and three of them have three or more observations.

Another interesting parameter to observe is the maximum magnitude observed for each star. In figure 3 we see that most of the novae are observed with a maximum magnitude over 20 (remind that bigger magnitude implies weaker observation) and this weak observations usually coincide with the novae with less observations.

In the following table we summarize the results per novae. We have only included the novae from the Max Planck database with which we have found real coincidences. The first column is the nova name, the second column indicates the maximum observed magnitude and the third column counts the number of matches we have found for each nova in our data.

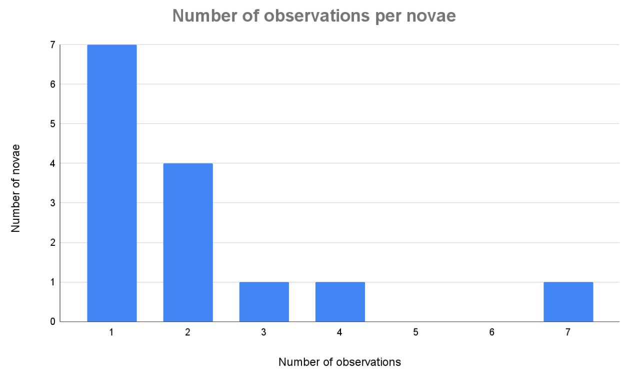


FIG. 2. Novae classified by number of observations of each.

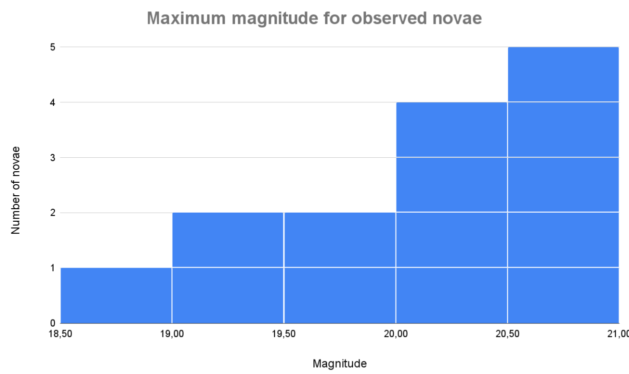
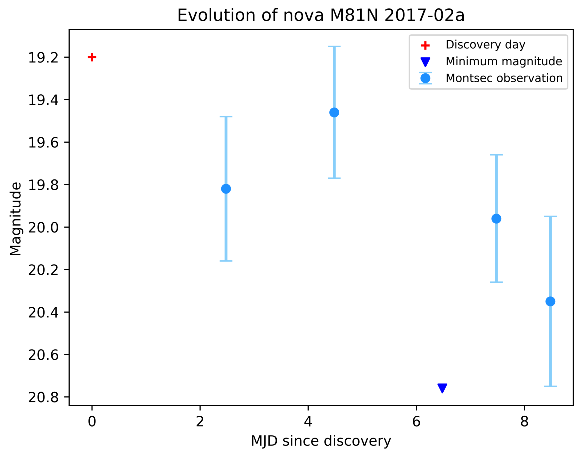


FIG. 3. Histogram of the number of novae classified by maximum magnitude of observation.

Novae observations		
Nova name	Max. obs. mag.	# of obs.
2018-04b	19,8	1
2018-03b	20,5	2
2018-03a	20,4	1
2018-02a	18,5	7
2018-01a	20,2	2
2017-04b	20,2	1
2017-04a	20,5	2
2017-02a	19,4	4
2017-01a	19,4	1
2016-12b	20,8	1
2016-11d	20,8	3
2016-11a	20,6	1
2016-10a	20,0	2
2016-06a	19,5	1

TABLE I. Novae coincidences summary.

In the next two figures (2 and 3) we show the results obtained for the novae M81 2017-02a and M81 2018-02a, respectively and then we will comment them.



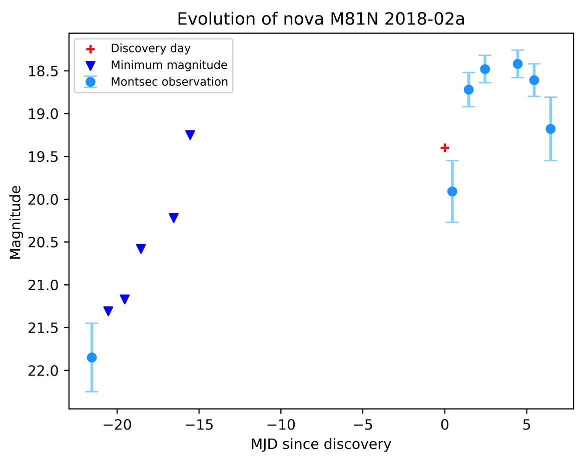


FIG. 4. Observations for two different novae: 2017-02a (above) and 2018-02a (below).

In the previous section, we commented the information that appears in the plots, so we can proceed on commenting the results for each nova.

In the case of the M81 2017-02a nova we have an observation around 2 days after the discovery day. We detect it passed 4, 7 and 8 days. We see that in the observation between the 6^{th} and the 7^{th} day we do not detect the nova despite the minimum magnitude that day was around 20.7 whereas the observed magnitude for this nova was around 19.5-20 the previous and following days and so, it should had been detected. This can be due to an imprecision of the algorithm or in the data that day, but we cannot know it. Except for that, the evolution of the magnitude of the nova seems correct. We start with low magnitude, increase a little and then descent again (note that the magnitude of the discovery date cannot be directly compared with the observed, as it does not come from the same telescope).

As for the second figure, from M81 2018-02a, after the discovery day we have 6 observations. They follow a similar evolution of magnitude as in the case of the M81 2017-02a, with the 6 observation in the 7 days after the discovery. Around 21 days before the discovery day, we have an observation match with the same coordinates as M81 2018-02a and a very low magnitude of around 21.8. The days after in which we had observations, the minimum magnitude observed those days was greater that 21.8. Therefore, we suggest that this nova could have been discovered before its official discovery day, although it was with a very low magnitude.

A parameter that is usually used for studying the evolution of the novae is the time that it takes for the magnitude to decay 2 units from its maximum value. In our case, as we have not got many observations, it does not make much sense to calculate it, but we can give an estimation of the time that it takes for the magnitude to decay 1 unit. For example, in the first case, the nova M81N 2017-02a has its maximum magnitude in the second observation, in around 19.4 and the last observation in around 20.4. So, it takes approximately 4 days to decrease 1 point of the magnitude. In the other nova, the maximum value is obtained in the 4^{th} observation after the discovery, at around 18.5. The last observation has a magnitude of approximately 19.2 and between them there are two days. Making a simple linear estimation, it would take almost 3 days from the maximum magnitude to decay 1 unit.

VI. CONCLUSIONS

The goal of the project was to observe the evolution of novae with the photometric data from Montsec telescope and comparing it with the catalogue of Max Planck Institute. We have not obtained a big quantity of novae with good observations. However, in the ones that we have (or we have found) good observations, we have clearly seen the evolution of the magnitude of observation of the novae.

The project has brought us the opportunity to get to know better what are novae, what is the work that is performed in order to study them and also to refresh some of our programming skills.

VII. BIBLIOGRAPHY

[1] Jordi José; Margarita Hernanz. Nucleosynthesis in classical novae: Co versus one white dwarfs. `https://arxiv.org/abs/astro-ph/9709153`, February 1998.

[2] Sumner Starrfield. Cno abundances and hydrodynamic models of the nova outburst. ii-1.00 solar mass models with enhanced carbon and oxygen. `http://adsabs.harvard.edu/pdf/1974ApJS...28..247S`, 1974.

[3] Glòria Sala; Margarita Hernanz. Models for the soft x-ray emission of post-outburst classical novae. `https://www.aanda.org/articles/aa/pdf/2005/33/aa2622-04.pdf`, 12 April 2005.

[4] A. W. Shafter et. al. A spectroscopic and photometric survey of novae in m31. `https://iopscience.`

iop.org/article/10.1088/0004-637X/734/1/12/pdf, 19 May 2019.

[5] Michael M. Shara et. al. The early palomar program (1950–1955) for the discovery of classical novae in m81 : Analysis of the spatial distribution, magnitude distribution, and distance suggestion. https://iopscience.iop.org/article/10.1086/316449/pdf, 27 May 1999.