OPEN EUROPEAN JOURNAL ON VARIABLE STARS
March 2022 http://oejv.physics.muni.cz ISSN 1801-5964
DOI: 10.5817/OEJV2022-0222

VARIABILITY OF L261 IN M 13

VIOLAT-BORDONAU, FRANCISCO

Observatorio Astronómico *Norba Caesarina*, 10195, Cáceres, Spain, fviolat@gmail.com

Abstract: After the discovery in April 2021 of the variability of the star L199 (now V63), belonging to the globular cluster Messier 13 (NGC 6205), between June and October 2021, we have studied twenty of the brightest stars, excluding the well-known red giant variables: surprisingly a good part of them shows some degree of variability in the range 0.05-0.25 magnitude in *V* band. In this work, we present light curves, average magnitudes, periods and amplitudes of the star L261 (2MASS J16413476+3627596), a red giant star located in the cluster, that we have studied using the CCD images obtained in the campaigns of 2019, 2020 and 2021, which we have joined the photometric measurements obtained by Osborn & Fuenmayor (1977), Kopacki *et al.* (2003), Deras *et al.* (2019) and ASAS-SN (from 2018 to 2021). The results suggest that this moderately bright star (average magnitude in 2021: 12.206 ± 0.027 *V*) is multiperiodic. It has at least two periods of different length which modulates its light curve over time: a period of variable duration (31 ± 5 days: between 26 and 36 days according to the campaign) joins another shorter (4.8 to 7.6 days) very marked in all the data sets used. With this discovery, Messier 13 now has 64 confirmed variable stars.

1 Introduction

Ludendorff 261 (Ludendorff, 1905), hereafter L261 (2MASS J16413476+3627596), is a red giant star located in Messier 13 from Gaia's parallax (Bailer-Jones *et al*., 2021), one of the brightest (*V*~5.8 mag.) and best known of the globular clusters in the constellation of Hercules (α = 16h 41' 41.24”, δ = +36º 27' 35.5”, J2000); the distance to the cluster was estimated as 7.1 ± 0.1 kpc, with an average metallicity of [Fe/H] = -1.58 ± 0.09 and an age of 12.6 Gyrs (Deras *et al*., 2019). Photographically L261 is a moderately bright giant star located at the edge of the densest part of the cluster (Fig.1), close to Cepheid star V2 (V1553 Her). In the literature, it appears with magnitude 12.23 *V* (Kadla, 1966), 12.23 *V* (Cudworth & Monet, 1979), 12.20 *V* (Osborn, 2000), 12.207 *V* in the paper of Sandquist *et al*. (2010), 12.20 in *V* (Deras *et al*., 2019), and 12.170 *V* in the paper of Stetson *et al*. (2019). None of the photometric studies carried out on the cluster before the year 1977 mentioned that it is variable. Osborn and Fuenmayor (1977) measured photographically in 54 plates of M 13 the magnitude *B* of four “nonvariable” stars (L250, L261, L370 and L845), and a suspect variable (L414) in the years between 1967 and 1969. Although they announced "not to find obvious evidence of variability" in them (and “variability could not be confirmed for L 414“) examining their measurements and plotting their light curves, it is very evident to us that L414 and L261 vary: the first with an amplitude equal to 0.26 ± 0.06 magnitude and the second with 0.21 ± 0.05 magnitude, both in *B* band. For the first, they found a possible period equal to 105 days and for the second equal to 50 days.

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
March 2022 http://oejv.physics.muni.cz ISSN 1801-5964
DOI: 10.5817/OEJV2022-0222

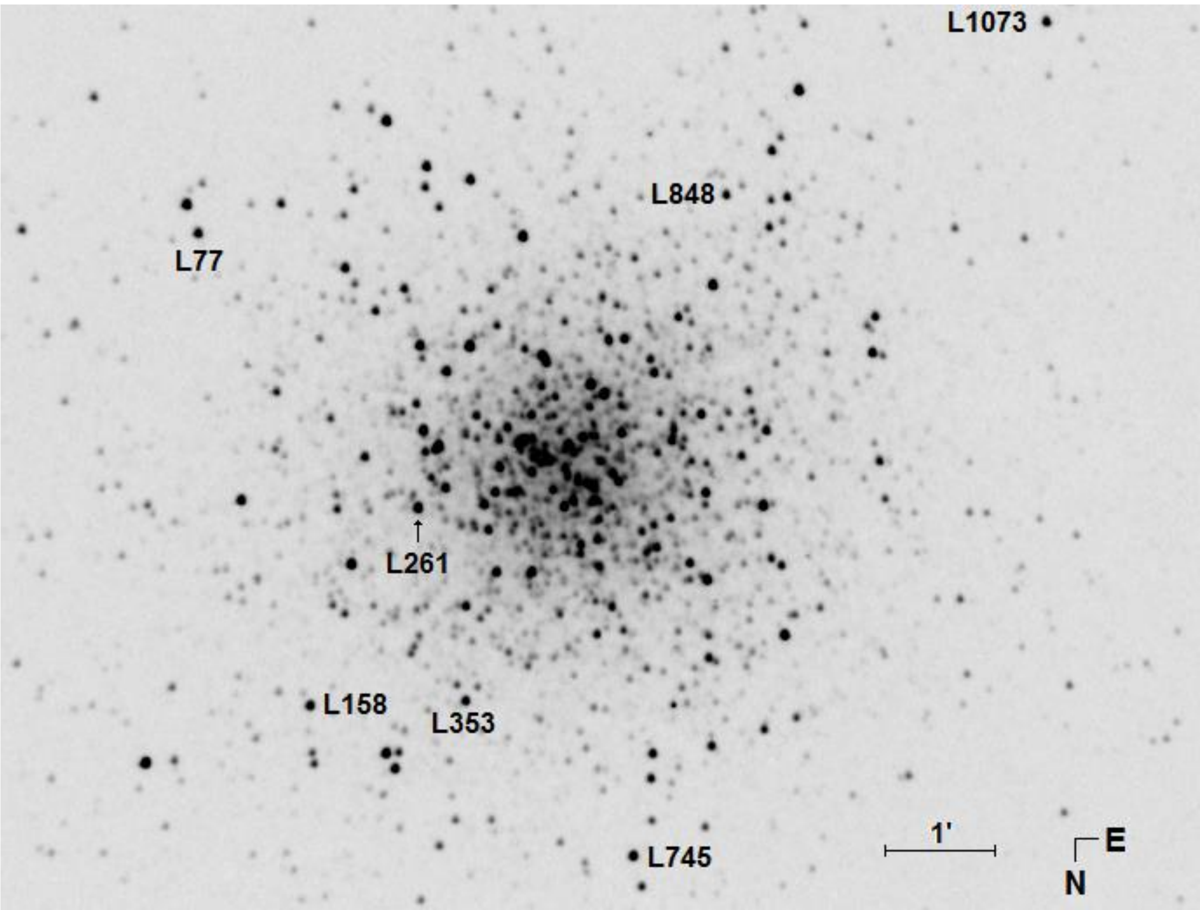


Figure 1: The observed field of Messier 13 with labelled stars: L261 (the new variable), L745, L158, L77, L353, L848 and L1073. North is down and East to the right.

Russeva & Russev (1980) investigated the behaviour of two variables (V10 and V15) and nine red giants, including L240, L261 and L414, using 43 blue plates taken between 1974 and 1978: they found suspected variability for L72 (now V18), L240 and L261. In the paper by Welty (1985), no variability was detected for L199 (V63), L240 (V59), L414 (V38) and L261 up to its detection limit ($\gtrapprox$0.2 magnitude in *B* band). In the paper by Lupton *et al*. (1987), two radial velocities measurements are tabulated, from which it was concluded that it is a probable variable. In Osborn's paper (2000), it does not appear as a variable either, being its standard deviations σ equal to 0.02 in *V* and 0.04 in *B*: if it was a variable star its amplitudes ΔV and ΔB would be very small (<0.1 mag), in agreement with Welty's (1985) less accurate photometry for this star. Kopacki *et al*. (2003) studied the cluster in 23 nights, between 2001 February 27 and August 1, collecting 324 and 342 frames in the I_C and *V* bands, respectively: they found L261 as constant in good agreement with Osborn's (2000) photometry for this star. Deras *et al*. (2019) studied the cluster in different campaigns (2014 and 2016) with telescopes installed in India and Spain (Canary Islands) taking 954 measurements in *V*: they found 15 stars (tagged as "candidates" and numbered from C1 to

March 2022 OPEN EUROPEAN JOURNAL ON VARIABLE STARS
http://oejv.physics.muni.cz
DOI: 10.5817/OEJV2022-0222 ISSN 1801-5964

Table 1: Observational log

Year	H.J.D. Start	H.J.D. End	Nights	Images
2019	2458672.576	2458770.339	99	498
2020	2459005.665	2459136.337	132	691
2021	2459369.667	2459507.306	139	1246

C15) in those that detected small brightness oscillations (from 0.04 to 0.20 mag, exceptionally 0.44 mag in the case of C6), but their data were insufficient to determine periods or their real amplitudes. They named L261 with the label of C3: its amplitude was >0.10 mag in *V*. Finally, Stetson *et al*. (2019) indicate that its *variability index* (the probability that it is a variable star) is equal to 1.260 with a weight equal to 126.5: with these two values it should be a variable star. Our photometric measurements (2019-2021), as well as other similar data sets (Osborn & Fuenmayor, Kopacky *et al*., Deras *et al*., and ASAS-SN photometry), confirm this: L261 is a new variable star.

2 Observation and data reduction

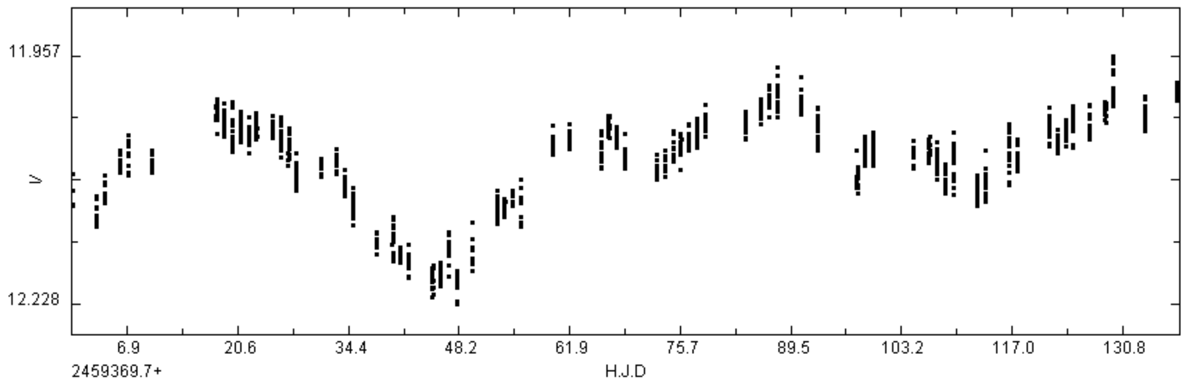
Since the spring of 2019, we have studied the variable very carefully and suspected variable stars of Messier 13: we employed the 0.2-m telescope of the Observatorio Astronómico *Norba Caesarina*, at Cáceres, Spain, located at 455 m above sea level, to obtain time-series imaging of the globular cluster. The image data were obtained during several runs between 2019 June and 2021 October, where we collected a total of 498 (2019), 691 (2020) and 1246 images (2021) through the Johnson *V* filter, respectively (see Table 1 for a detailed log of the observations): the exposure times were always 120 s. The CCD camera is a Starlight Xpress MXV-7, of 752 × 580 pixels, with a scale of 0.90”/pixel and a field of view of 11.4 x 8.5 $arcmin^2$ (Figure 1). The calibration of the frames consisted of the bias and dark subtraction and the flat-field correction.

The photometric data were reduced using the software *FOTODIF* [1] (FOTOmetría DIFerencial, differential photometry) and calibrated using three stars of very well determined *B* and *V* magnitudes (Table 2) published in the photometric study by Stetson *et al*. (2019). The CCD finder chart (with labelled stars) is shown in Figure 1: the magnitudes were determined relative to L745, L158 and L848, whose constancy during the run was confirmed using L77 (mag. 12.735 *V*), L353 (mag. 12.809 *V*) and L1073 (mag. 12.859 *V*). Table 2 presents the coordinates (J2000) of the variable, comparison and check stars taken from SIMBAD and their *V* magnitudes and *B* – *V* colour index from Stetson *et al*. (2019). This calibration procedure with three stars works perfectly: in Figure 2, we present the light curves of the variable stars V33 (upper panel) and V38 (lower panel) throughout the 2021 campaign; in

[1] Written by Julio Castellano, http://www.astrosurf.com/orodeno/fotodif/index.htm

Table 2: Variable, comparison, and check stars

Star	ID	RA (J2000) [h:m:s]	DEC (J2000) [° ' "]	*V* [mag]	*B* – *V* [mag]
L261	2MASS J16413476+3627596	16:41:34.76	+36:27:59.51	12.170	1.380
L745	2MASS J16414486+3630514	16:41:44.85	+36:30:51.37	12.490	1.293
L158	2MASS J16413053+3629434	16:41:30.52	+36:29:43.44	12.675	1.144
L77	2MASS J16412464+3625449	16:41:24.63	+36:25:45.11	12.735	1.141
L353	2MASS J16413725+3629368	16:41:37.24	+36:29:36.77	12.809	1.138
L1073	2MASS J16420085+3623338	16:42:00.84	+36:23:33.67	12.859	1.087
L848	2MASS J16414739+3625111	16:41:47.40	+36:25:11.13	13.110	1.071



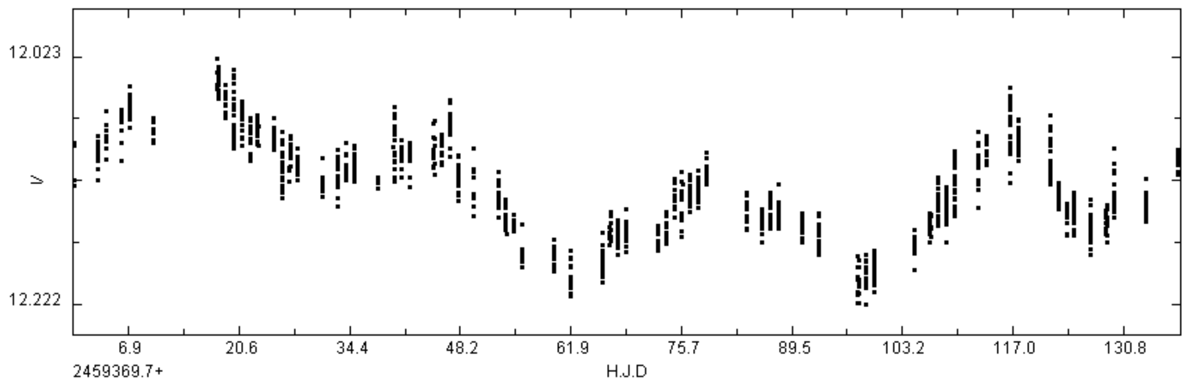


Figure 2: Light curves of the variable stars V33 (upper panel) and V38 (lower panel) obtained throughout the 2021 photometric campaign: both are semiregular red giants.

both we can see the behaviour of both stars over the weeks, and both are coherent without showing any strange or unexpected effect on them.

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
http://oejv.physics.muni.cz
DOI: 10.5817/OEJV2022-0222
ISSN 1801-5964

Table 3: Periods of the variable L261 (days)

Year	Points	P1	P2	P3	P4
2019	498	36.1	19.4	13.6	4.7
2020	691	54.4	27.1	5.1	17.5
2021	1246	147.5	25.9	7.1	40.5

3 Data analysis

After the discovery in April 2021 of the new variable V63 (Violat-Bordonau, 2021), we decided that during the 2021 campaign, which would extend between May and November, we would study (in addition to all the already known variables – red giants, Cepheids and RR Lyraes – to obtain their light curves, mean magnitudes, amplitudes, and periods) twenty of the brightest stars in the cluster finding for signs of variability in them. We can mention L169, L198, L201, L222, L250, L252, L261, L262, L296 and others. At the end of the campaign, with the arrival of the rain, in mid-October, we began to measure the CCD images, obtaining many files with the *V* magnitudes of all these stars. When we plotted their light curves, we were astonished to see that a good part of them showed variability, although their amplitude was quite small (from 0.05 to 0.25 magnitude). In the present work, we analyze the behaviour of the variable star L261, leaving the rest of the variables that we have confirmed or discovered for future works. The number of photometric measurements obtained is enormous: between 1230 and 1246 per star for a total of sixty-two stars (although we are now expanding this number by analyzing stars of fainter magnitudes). After plotting the light curve of L261 with the data for the year 2021, we decided to measure the CCD images obtained in the 2019 and 2020 campaigns: with this data, we obtained three files that we analyzed to plot their light curves (Figure 3) and determine their average *V* magnitudes, periods and ranges of variation (amplitude). The periodogram analysis of the photometric data was made by *AVE* [2] using the Scargle algorithm (Scargle, 1982); the search in the interval 1 to 150 days (Figure 4) gave us the four most important periods in each campaign, which we present in Table 3.

Although two of the most outstanding seem to be *long periods* (54.4 and 147.5 days in 2020 and 2021, respectively), by drawing the light curves with them, no valid results were obtained. After the initial surprise, we verified that the only values that allowed us to get light curves with a certain quality were the ones we could call *short periods* (from 25.9 to 36.1 days). We find the explanation when we check with surprise that three *very short* periods (from 4.7 to 7.1 days), which appear in all the periodograms, interact with the *short periods* producing a modulation in the light curves throughout the campaign and even of a campaign to another (Figure 3).

[2] "Análisis de Variabilidad Estelar", written by Rafael Barberá, Grupo de Estudios Astronómicos, G.E.A.

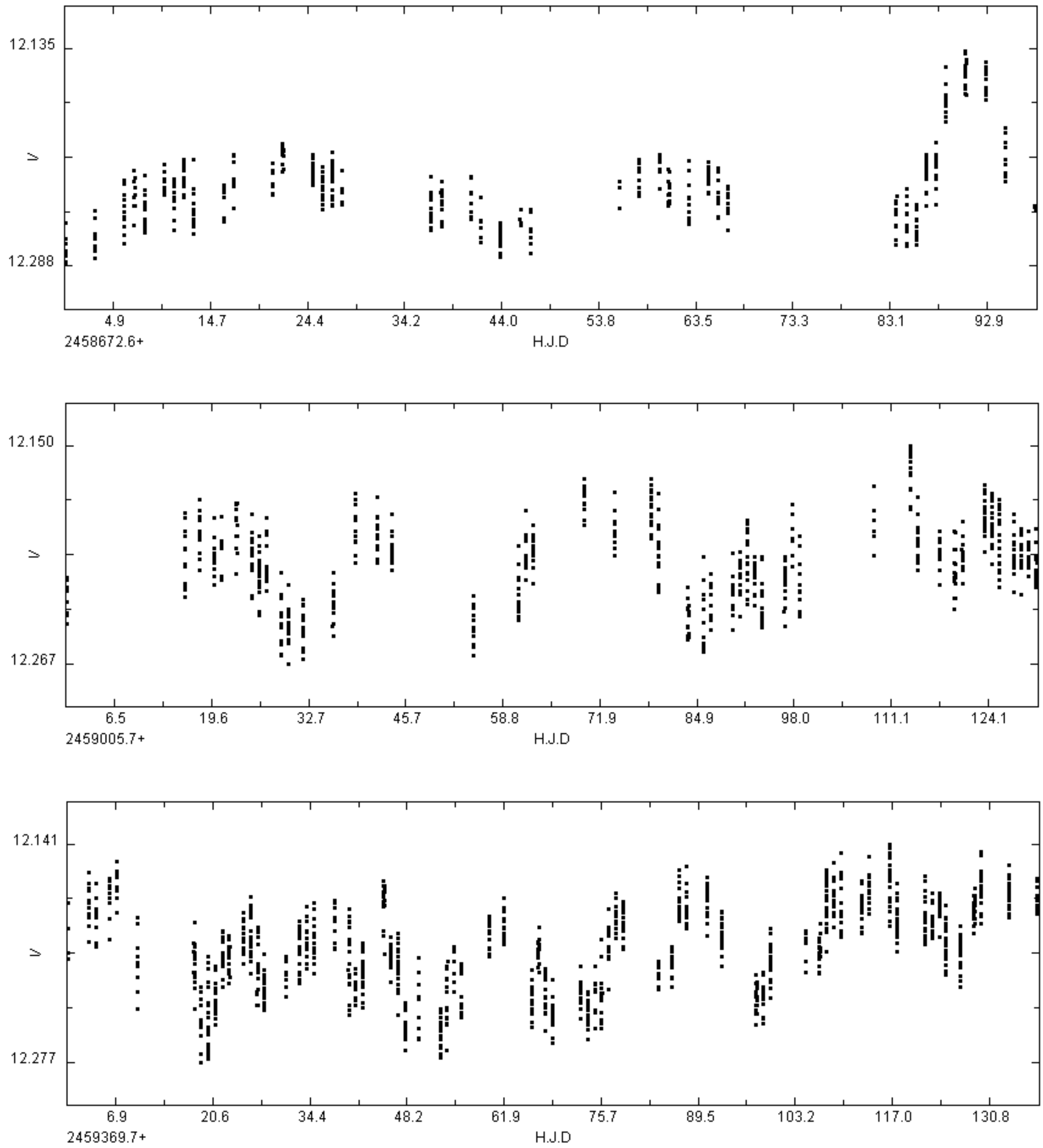


Figure 3: Light curves of the variable star L261 in 2019 (upper), 2020 (middle) and 2021 (lower panel): changes in light curves are very noticeable of one campaign to another.

When, later, we analyze the photometric measurements of Osborn and Fuenmayor (1977), Kopacki *et al*. (2003) and ASAS-SN (2016-2021) we will check the existence of these *very short* periods in them (and especially in the last data set). In Table 4 we summarize the photometric parameters (average *V* magnitudes, amplitudes, and ranges of variability Δ*V*) of the new variable star determined from our measurements.

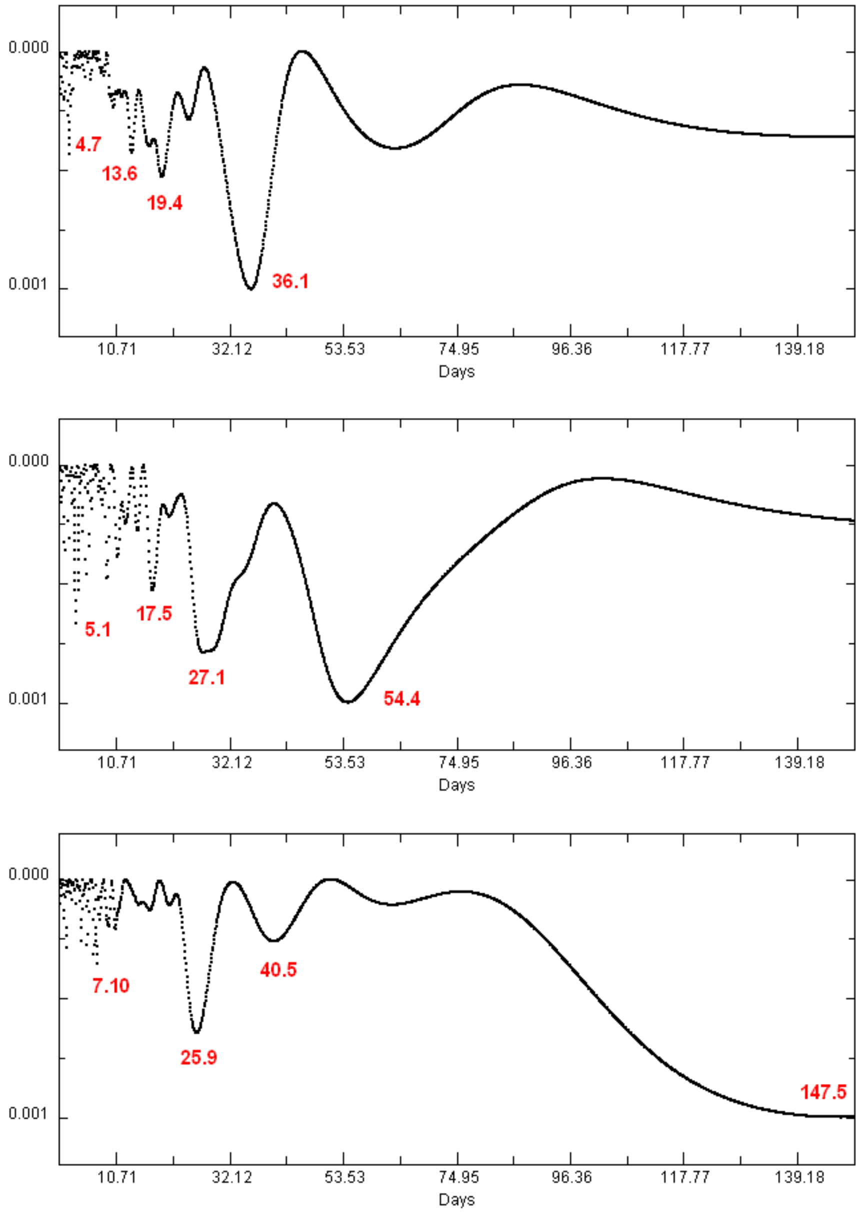


Figure 4: Scargle periodogram of the new variable L261 obtained for the interval 1–150 days in the campaigns of the years 2019 (upper), 2020 (middle) and 2021 (lower panel).

Table 4: Average *V* magnitudes, amplitudes and ranges of variability (Δ*V*)

Year	*V* [mag]	Amplitude [mag]	Δ*V* [mag]
2019	12.238 ± 0.021	0,153	12.135-12.288
2020	12.213 ± 0.022	0.117	12.150-12.267
2021	12.206 ± 0.027	0.136	12.141-12.277

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
March 2022 http://oejv.physics.muni.cz ISSN 1801-5964
DOI: 10.5817/OEJV2022-0222

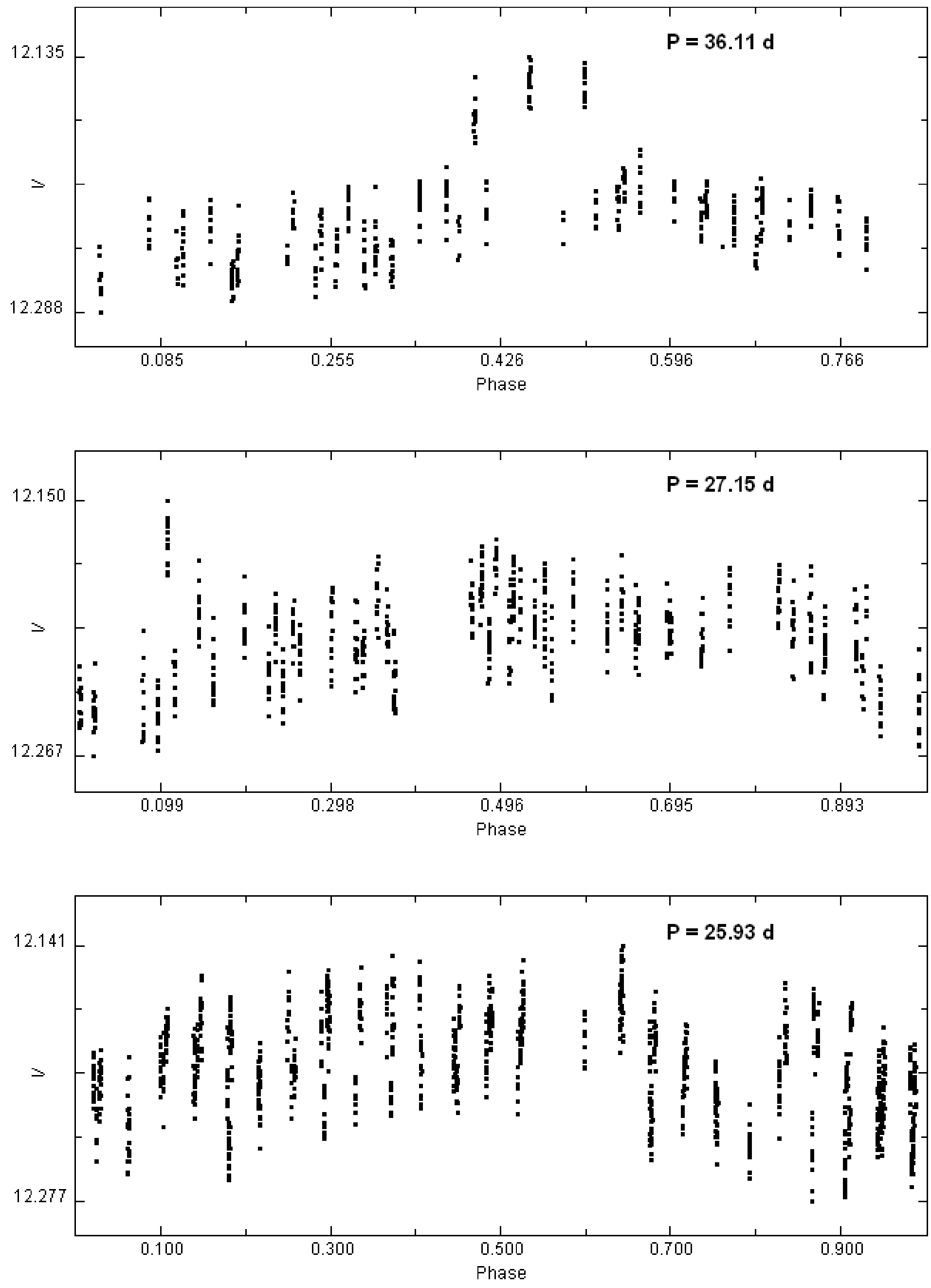


Figure 5: Light curves of the new variable star L261, plotted in phase, using the measurements and the most outstanding periods of each campaign: 2019 (upper), 2020 (middle) and 2021 (lower panel).

Using the three *short periods* obtained (36.11 days in 2019, 27.15 days in 2020 and 25.93 days in 2021), we have plotted the light curves of the new variable L261 in phase (Figure 5). None of them is of good quality due to the modulation produced by the *very short* period already mentioned but allow us to verify that the star is a variable of small amplitude (<0.155 magnitude in *V*).

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
March 2022 http://oejv.physics.muni.cz ISSN 1801-5964
DOI: 10.5817/OEJV2022-0222

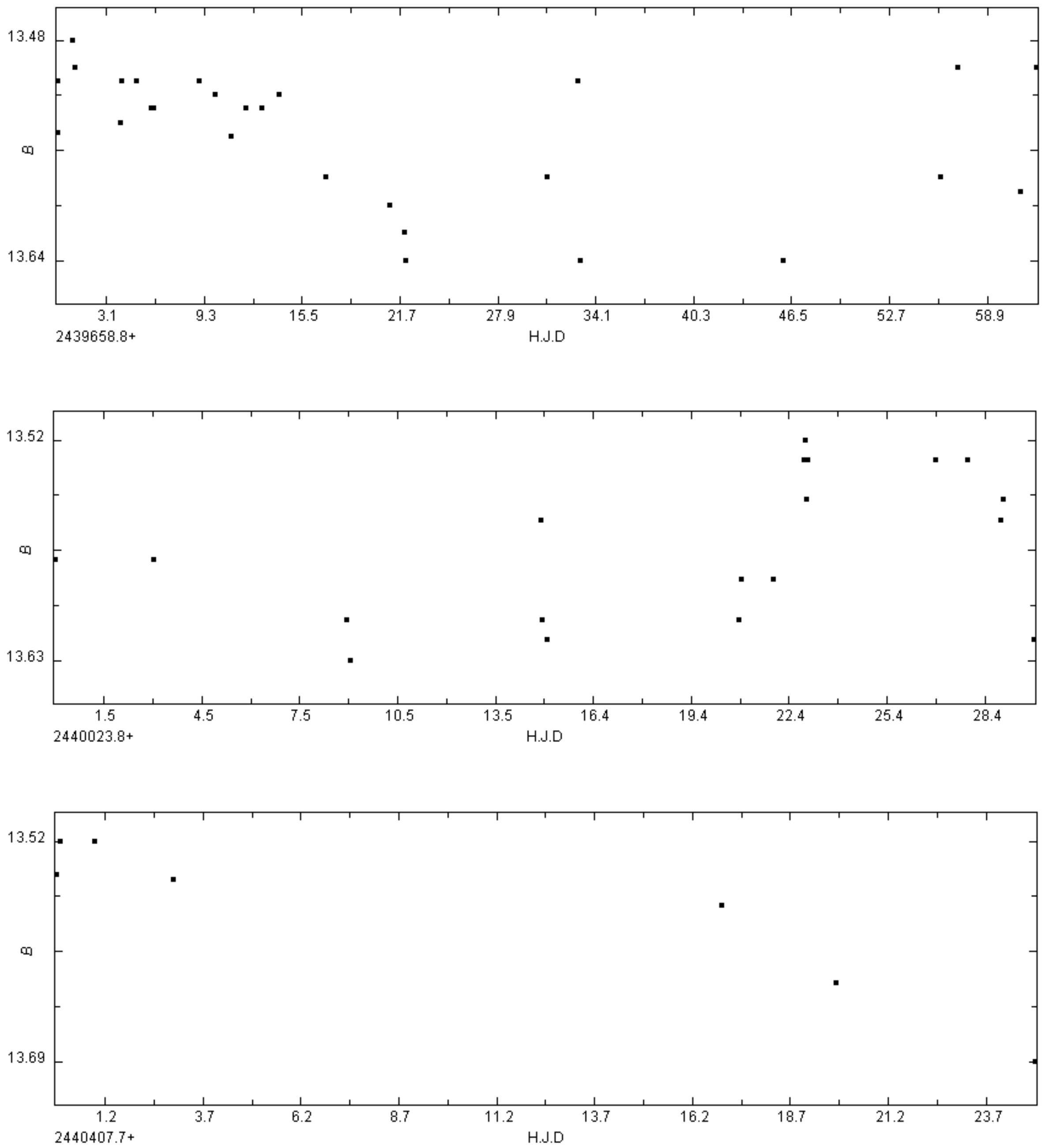


Figure 6: Light curves of the new variable star L261 plotted from measurements of Osborn and Fuenmayor (1977), in *B* band, of the years 1967 (upper), 1968 (middle) and 1969 (lower panel).

To verify these results, we have used photometric measurements (in *B* band) published by Osborn and Fuenmayor (1977), with which we have plotted their light curves in the years 1967, 1968 and 1969 (Figure 6) and checked its variability: the visual inspection of these light curves (especially the year 1969) demonstrates this variability. After analyzing these data with *AVE*, we have obtained its periodogram (Figure 7, upper panel): we can see two

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
March 2022 http://oejv.physics.muni.cz ISSN 1801-5964
DOI: 10.5817/OEJV2022-0222

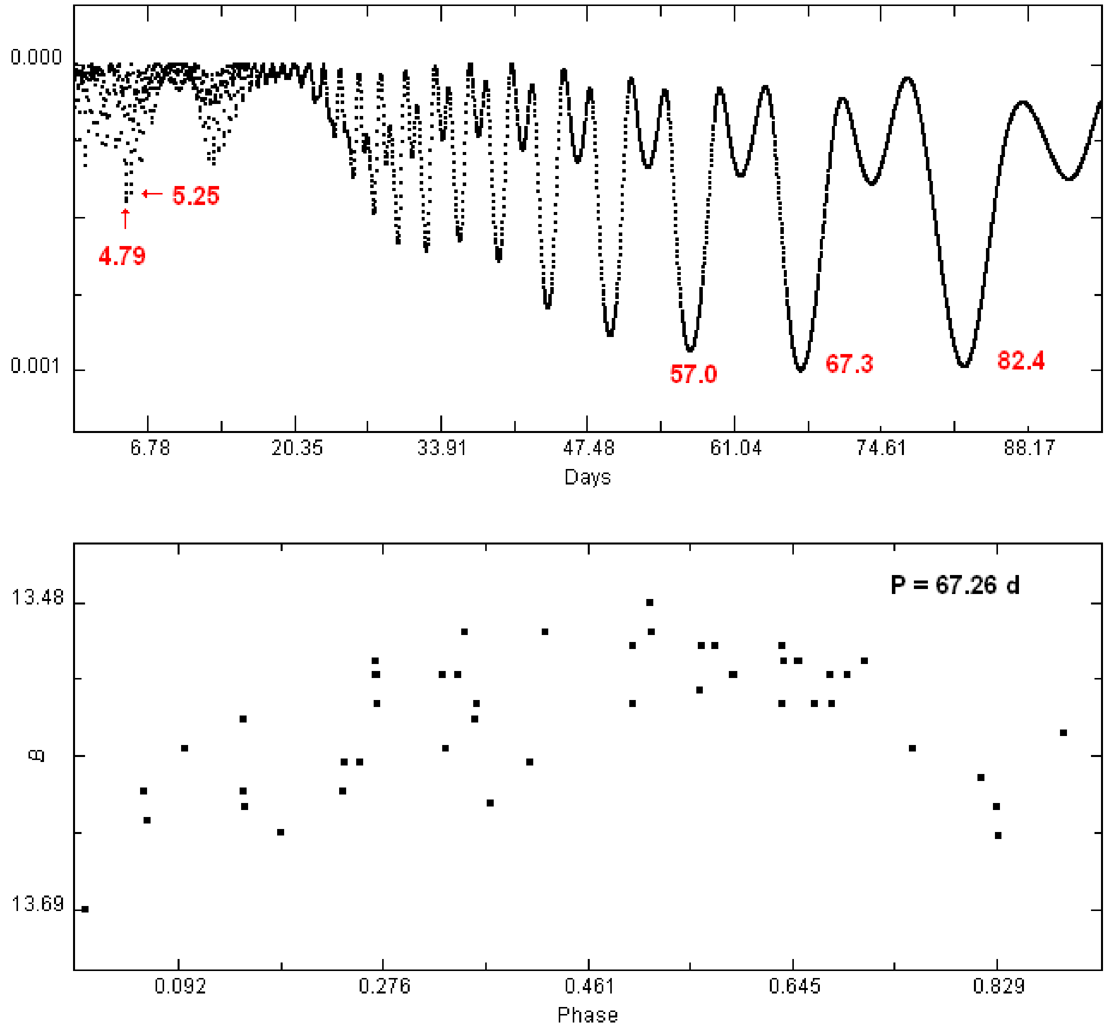
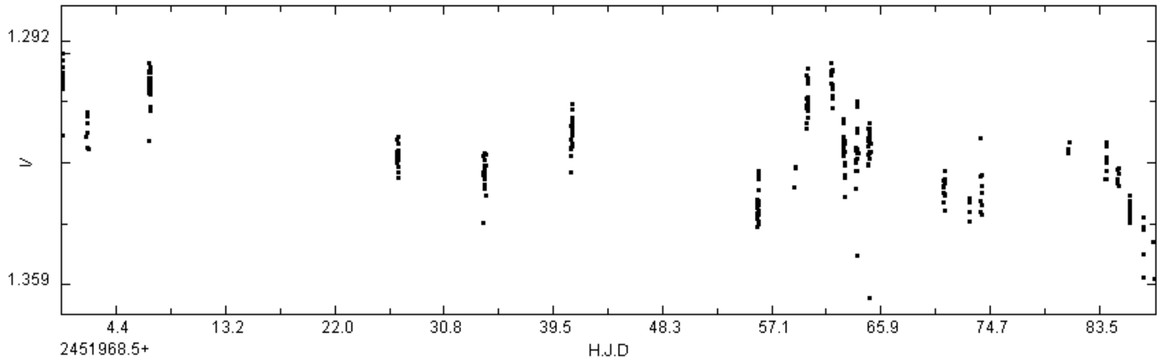


Figure 7: Periodogram obtained from the photometric measurements of Osborn and Fuenmayor (upper panel) and light curve, in *B* band, plotted in phase with a period equal to 67.26 days (lower panel).

very short periods equal to 4.79 and 5.25 days and another *long period* equal to 67.3 days, with which we have plotted a good quality light curve (Figure 7, lower panel).

These results are similar and agree with ours, including the *very short* periods (4.79 and 5.25 days) and the small amplitude (0.21 magnitude in *B* band). Kopacki *et al*. (2003) indicated in their study that L261 is "constant in light": our data showed some variability, within a range of 0.12-0.15 magnitude in *V*. However, no "perfect" regular period could be deduced from the data. To check the behaviour of the new variable over time, we have taken photometric measurements in *V* band, published by Kopacki *et al*., which we show on the upper panel of Figure 8 (authors express ordinate in arbitrary flux units). After obtaining the periodogram with *AVE* (Figure 8, lower panel), we see that there are several *very short periods* (two in this case: 5.9 and 7.6 days) and another *short period*, very marked, equal to 18.7 days. Although its amplitude in this band is very small (only 0.067 magnitude in *V*), L261 is variable and agrees with our results and those of Osborn and Fuenmayor.

DOI: 10.5817/OEJV2022-0222



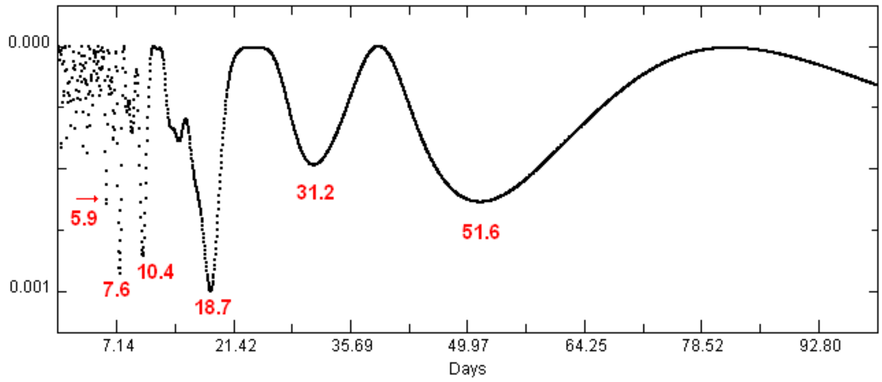
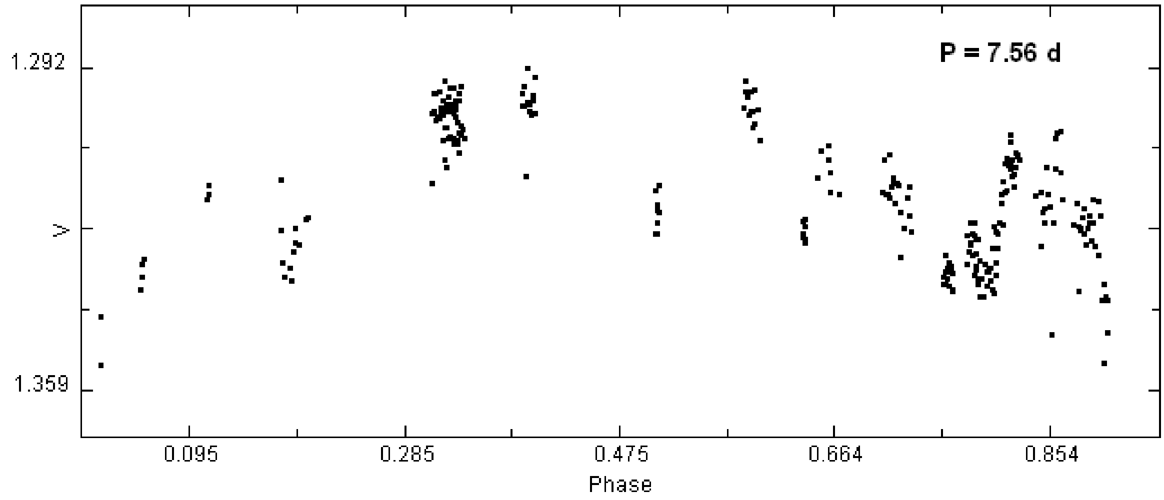


Figure 8: Light curve plotted from the photometric measurements of Kopacki et al. in *V* band (upper panel) and periodogram obtained with *AVE* (lower panel).

Using the most prominent *very short period* (7.56 days) and the most outstanding *short period* (18.67 days), we have proceeded to draw their light curves in phase, which we show in Figure 9. None of them is of good quality, like all the light curves that we have obtained and plotted so far (due to the interaction between them: both among the two or three *very short periods* as the *short periods*), but clearly show the variability of the star and its small amplitude in *V*. Deras *et al*. published a paper in 2019 in which they detected a very low variability in L261 (to which they labelled with the name of C3), but they did not determine their period. They classified the star L261 as a variable of type SR. The Hertzsprung-Russell diagram draws the star near the top of the branch of red giants (Figure 12 in the paper mentioned above). Table 3 of this work indicated that “their variation is rather conspicuous”, and its amplitude was larger than 0.10 magnitude in the V band: it agrees with the results already shown (our data, Osborn & Fuenmayor and Kopacki et al.).

March 2022 OPEN EUROPEAN JOURNAL ON VARIABLE STARS
http://oejv.physics.muni.cz
DOI: 10.5817/OEJV2022-0222 ISSN 1801-5964



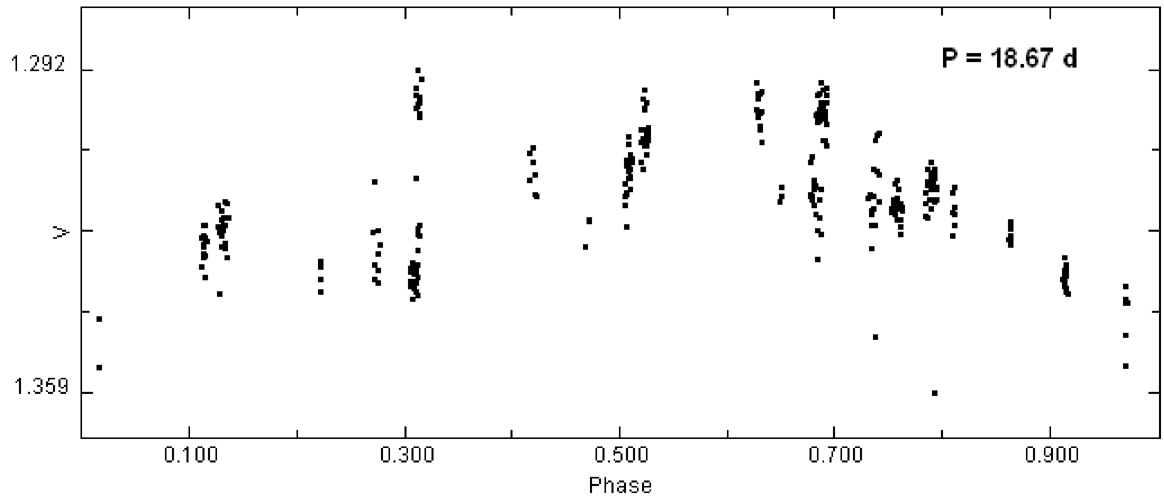


Figure 9: Light curves, in phase, plotted with the Kopacki *et al*. measurements using a period equal to 7.56 days (upper panel) and 18.67 days (lower panel).

Finally, to confirm, improve and refine our results, we have downloaded the ASAS-SN (*All-Sky Automated Survey for SupeNovae*) measurements in *V* and Sloan *g*-band (Shappee *et al*., 2014; Jayasinghe *et al*., 2018b), obtained between 2016 and 2021. For this work, we have analyzed only the measurements in *g*-band (2018-2021) because they are more numerous than those obtained in *V* (2016-2018) and cover four full campaigns, three of them (2019, 2020 and 2021) in the same years that we have worked. After eliminating some anomalous measurements (differed from the others in several tenths of magnitude) we get a total of 2510 points distributed in four campaigns (January 2018 to November 2021) that we show in Figure 10.

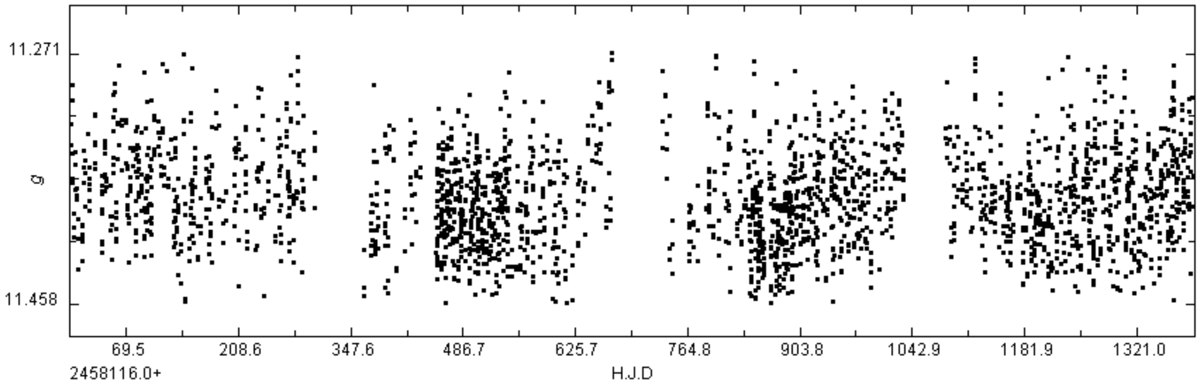


Figure 10: Light curve plotted from the photometric measurements of ASAS-SN, in *g* band, from 2018 to 2021: its small amplitude is equal to 0.187 magnitude.

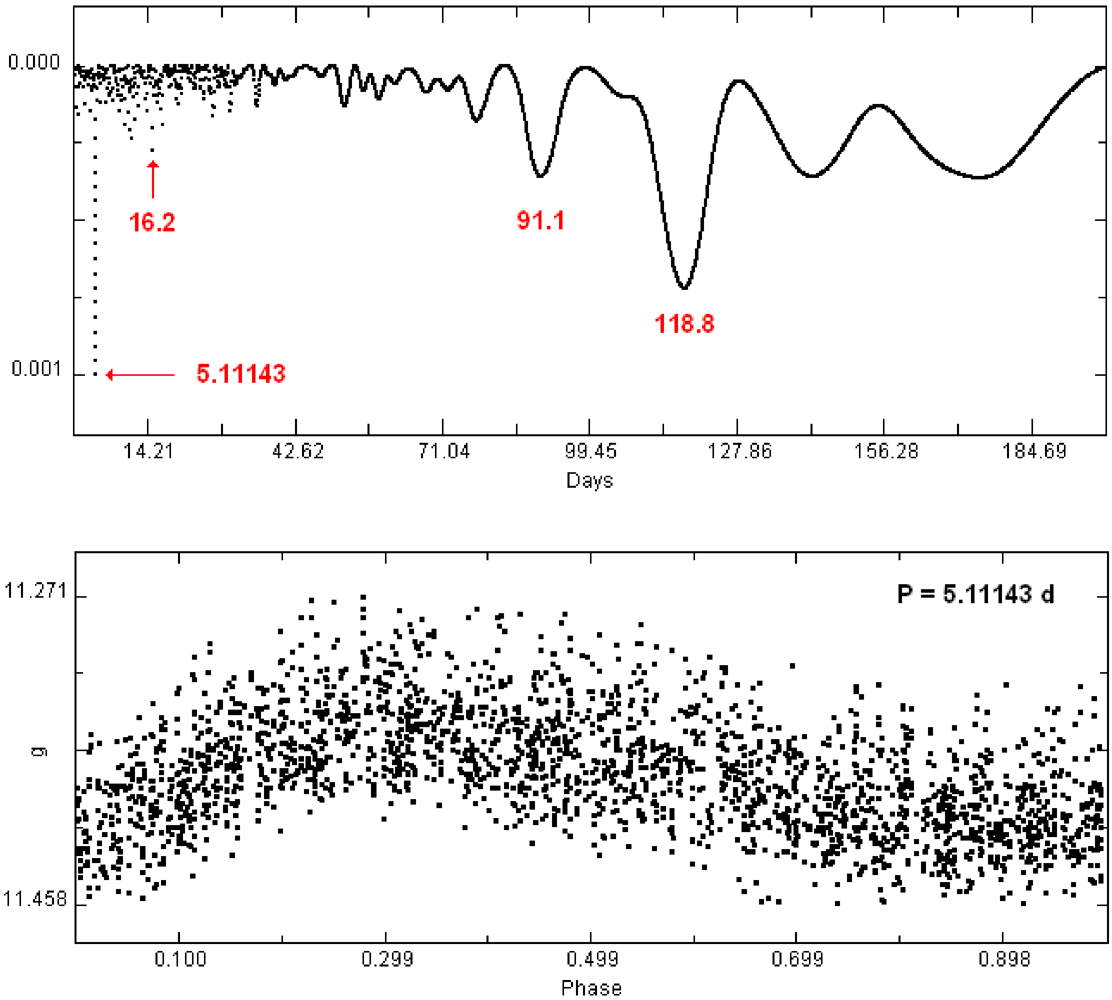


Figure 11: Periodogram obtained with *AVE* (upper panel) and light curve, in phase, plotted with ASAS-SN data using a period equal to 5.11143 days (lower panel): it appears moderately coherent with an amplitude equal to 0.187 magnitude.

As in the previous cases, we have analyzed this data with *AVE* and obtained a periodogram, which we show in the upper panel of Figure 11. The reader will notice a *very short period*, also outstanding, equal to 5.11143 days similar (in some cases almost identical) to which they also appeared in the other data sets already presented and analyzed. Using this value on the measurements is obtained a pretty good quality light curve displayed on the lower panel of the same Figure 11: his average magnitude is equal to 11.739 ± 0.036 *g*. This asymmetric light curve (we have plotted its maximum in phase 0.3 and minimum in phase 0.9 to enhance this effect) is very similar to that of the Cepheid V2 (V1553 Her, a W Virginis stars) that in Messier 13 it appears very close. Naturally, L261 is a red giant star and not a Cepheid! This variable displays a *short*-term variation, but a *very short*-term variation is also very evident, especially and with notoriety, in ASAS-SN data. The *very short*-term variations might be due to the binary nature of the star.

4 Conclusions

From the photometric measurements of Messier 13 (NGC 6205), obtained from the Observatorio Astronómico *Norba Caesarina* (Cáceres, Spain) in 2019, 2020 and 2021 campaigns, we have confirmed, and we report the variability of the star L261 (2MASS J16413476+3627596), a red giant of magnitude 12.21 *V* member of the cluster. Also, we found that all cluster red giants brighter than about ~12.65 mag in *V* and $B - V > 1.35$ are variable: show some degree of variability, although with very small amplitudes (from 0.05 to 0.25 magnitude in *V*). From our data, confirmed with photometric measurements from Osborn & Fuenmayor (1977), Kopacki *et al*. (2003), Deras *et al*. (2019) and ASAS-SN (2018-2021), we determined an amplitude lower than 0.117 mag. (2020) and 0.153 magnitude (2019) in the Johnson *V* band. The light curves suggest the presence of more than one period. The star changes its brightness with a period equal to 31 ± 5 days (between 26 and 36 days in the period 2019-2021) but without a regular periodicity, very typical of this type of giant star that in the case of Messier 13, oscillate between 27 (V63) and 92 days (V11). Most of the red variable stars of the cluster are overtone pulsators, and some of them may have multiple periods (Osborn *et al*., 2017).

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
http://oejv.physics.muni.cz
DOI: 10.5817/OEJV2022-0222
ISSN 1801-5964

Acknowledgements: This paper is based on observations obtained at the Observatorio Astronómico *Norba Caesarina* (MPC Z71) at Cáceres (Spain). We are indebted and want to express here our gratitute to Juan Luis González-Carballo (from the *Grupo de Observadores de Supernovas*) for his help, Dr. Wayne Osborn for valuable comments, and Dr. Dan Deras for sharing with us his measurements and his time. We are also grateful to the referee for valuable comments. This research has also made use of the SIMBAD database, operated at CDS, Strasbourg, France, ASAS-SN data and NASA's Astrophysics Data System Abstract Service. The observational data used in this work are available upon request to Francisco Violat-Bordonau (fviolat@gmail.com).

References

Bailer-Jones, C., *et al*., 2021, AJ, 161, 147: 2021AJ....161..147B
Cudworth, K. M., Monet, D. G., 1979, AJ, 84, 774: 1979AJ.....84..774C
Deras, D., *et al*., 2019, MNRAS, 486, 2791: 2019MNRAS.486.2791D
Jayasinghe, T., *et al*., 2018, MNRAS, 486, 1907: 2019MNRAS.486.1907J
Kadla, Z. I, 1966, Izvestiia Astron. Observ. Pulkove, 24, 93: 1966IzPul..24...93K
Kopacki, G., *et al*., 2003, A&A, 398, 541: 2003A&A...398..541K
Ludendorff, H., 1905, *Publ. Astrophys. Obs. Potsdam*, Vol. 15, Nº 50: 1905POPot..50....1L
Osborn, W., Fuenmayor, F., 1977, AJ, 82, 395: 1977AJ.....82..395O
Osborn, W., 2000, AJ, 119, 2902: 2000AJ....119.2902O
Osborn, W., *et al*., 2017, Acta Astronomica, 67, 131: 2017AcA....67..131O
Russeva, T., Russev, R., 1980, IBVS, 1769: 1980IBVS.1769....1R
Sandquist, E. L., *et al*., 2010, AJ, 139, 2374: 2010AJ....139.2374S
Scargle, J. D., 1982, ApJ, 263, 835: 1982ApJ...263..835S
Shappee, B. J., *et al*., 2014, ApJ, 788, 48: 2014ApJ...788...48S
Stetson, P. B., *et al*., 2019, MNRAS, 485, 3042: 2019MNRAS.485.3042S
Violat-Bordonau, F., 2021, OEJV, 213, 1: 2021OEJV..213....1V
Welty, D. E., 1985, AJ, 90, 2555: 1985AJ.....90.2555W