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NEW VARIABLE STARS IN MESSIER 13 (I) DERAS'S CANDIDATES C1 TO C5

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Abstract: We have studied the variable star candidates C1 to C5 (announced in 2019 by Deras *et al.*), located in Messier 13, using *V* band CCD images obtained in a campaign during 2023. We find very small amplitude modulations (0.068 mag for C5 to 0.083 mag for C4), consistent with the results obtained by its discoverers: >0.04 mag for C1 and >0.07 mag for the remaining ones. From their periodograms we can estimate their periods: three of them (C1, C4 and C5) present high values (from 60.89 to 140.56 days) while C2 is short: 8.90 days; these values are similar to those listed in the TESS and ZTF Catalogs for these stars. We have also analyzed the photometric measurements obtained by ASAS-SN between 2019 and 2023, in SLOAN-g band, identifying oscillations of reduced amplitude and obtaining excellent light curves for C4 and C5 in that period of time. In the Color-Magnitude diagram we find C4, one of the brightest stars in the cluster (M_V = –2.11 according to our photometry), located at the top of the Red Giant Branch such as other conspicuous variable stars (V11, V17, V24, V33...). This suggests that the brightest stars in the cluster (between magnitudes 11.95 and 12.55 *V*) are all variables, some of them of very small amplitude not previously identified as such, which we demonstrate with the discovery of V63 and V64 recently (2021 and 2022 respectively), and we will show for other bright stars is a future paper. As one of them (C3, now V63) was confirmed previously in 2021, and the last one in the electronic version of the *Catalog of Variable Stars in Globular Clusters* (CVSGC) is V65 (January 2024), we suggest for the remaining the names of V66, V67, V68, and V69.

1 Introduction

The purpose of this paper (the first of a series of three) is to investigate the variability of four (C1 to C5 except C3, whose variability we studied in a previous paper [Violat, 2022]) of the 15 candidate variable stars in Messier 13, presented in 2019, to confirm their variability (over 149 nights).

Recently, Deras *et al*. (2019, hereafter DER19) presented fifteen candidate variables in Messier 13, nominating them C1 to C15, with amplitudes ranging from 0.04 (C1 and C13) to 0.44 mag (C6) in the *V*-band. They provided α and δ coordinates (J2000) for these candidates, along with a precise chart of their locations (Figure 2 in their paper); these authors find that six of them (from C1 to C6) belong to the cluster. Figure 1 shows an image of the cluster, taken through the *V* Johnson filter with our telescope, in which we have identified both the comparison stars and the new variables: candidate C3 or L261 (Ludendorff, 1905) is now the variable star V64.

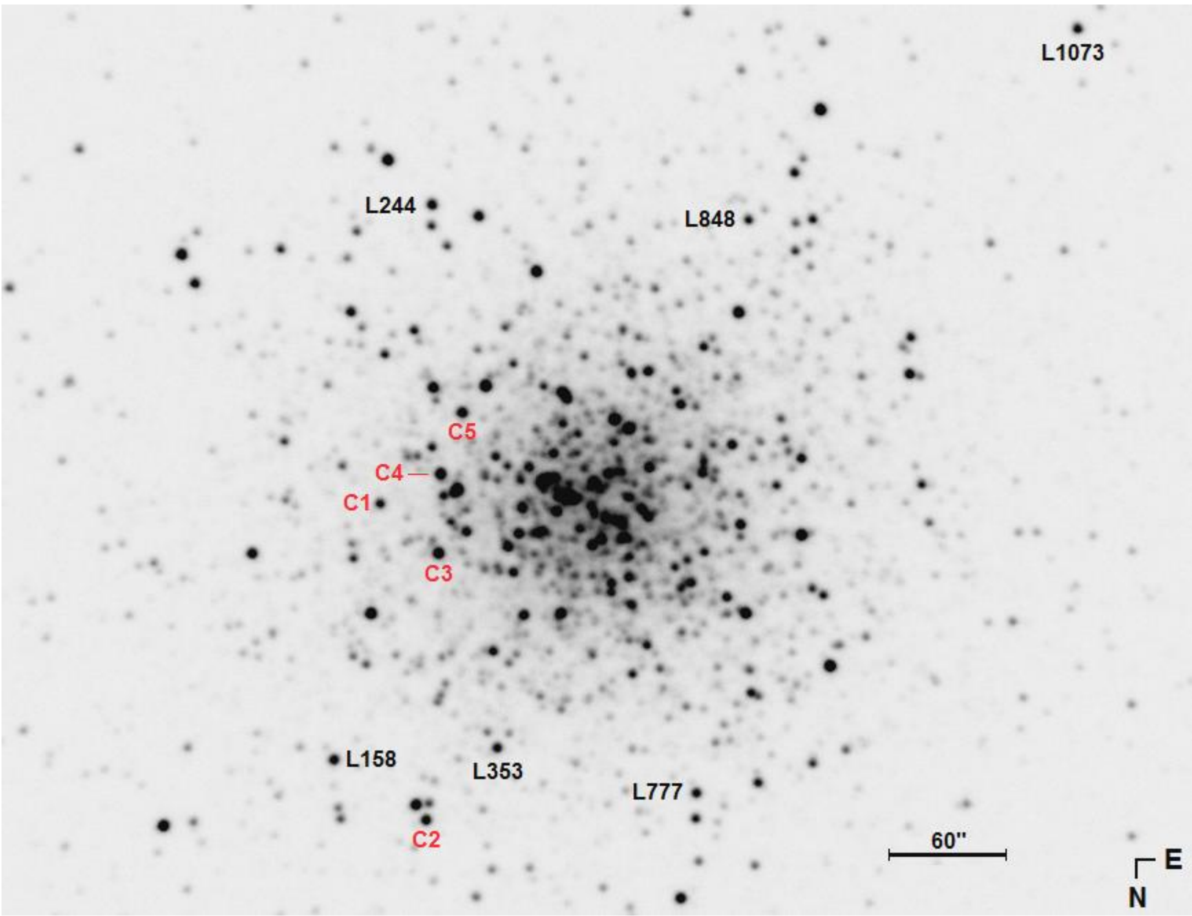

Figure 1: The CCD observed field of Messier 13 with labeled stars: candidates C1 to C5 (C3 = V64) and comparison stars L158, L244, L353, L777, L848 and L1073. North is down, East to the right.

Messier 13 is 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 (DER19). Its proximity allows small diameter telescopes (20 to 40 cm) to obtain photometry from their stars, on condition that the focal is sufficient to separate its components even close to its nucleus. If the accuracy of this photometry is high and the campaign is long enough (greater than 90-150 nights or even something else), we can identify and study new variables not recognized to date or even confirm candidates for variables, as in this case. Figure 2 shows light curves of the variables V33, V18, and V15 during the 2023 campaign: having observed almost every clear night, our precise photometry has allowed us to detect micro-changes of a few hundredths of magnitude in sixty different stars, including the variables already known, variable candidates and bright stars not detected as variables to date in the range 12.30-13.50 *V*.

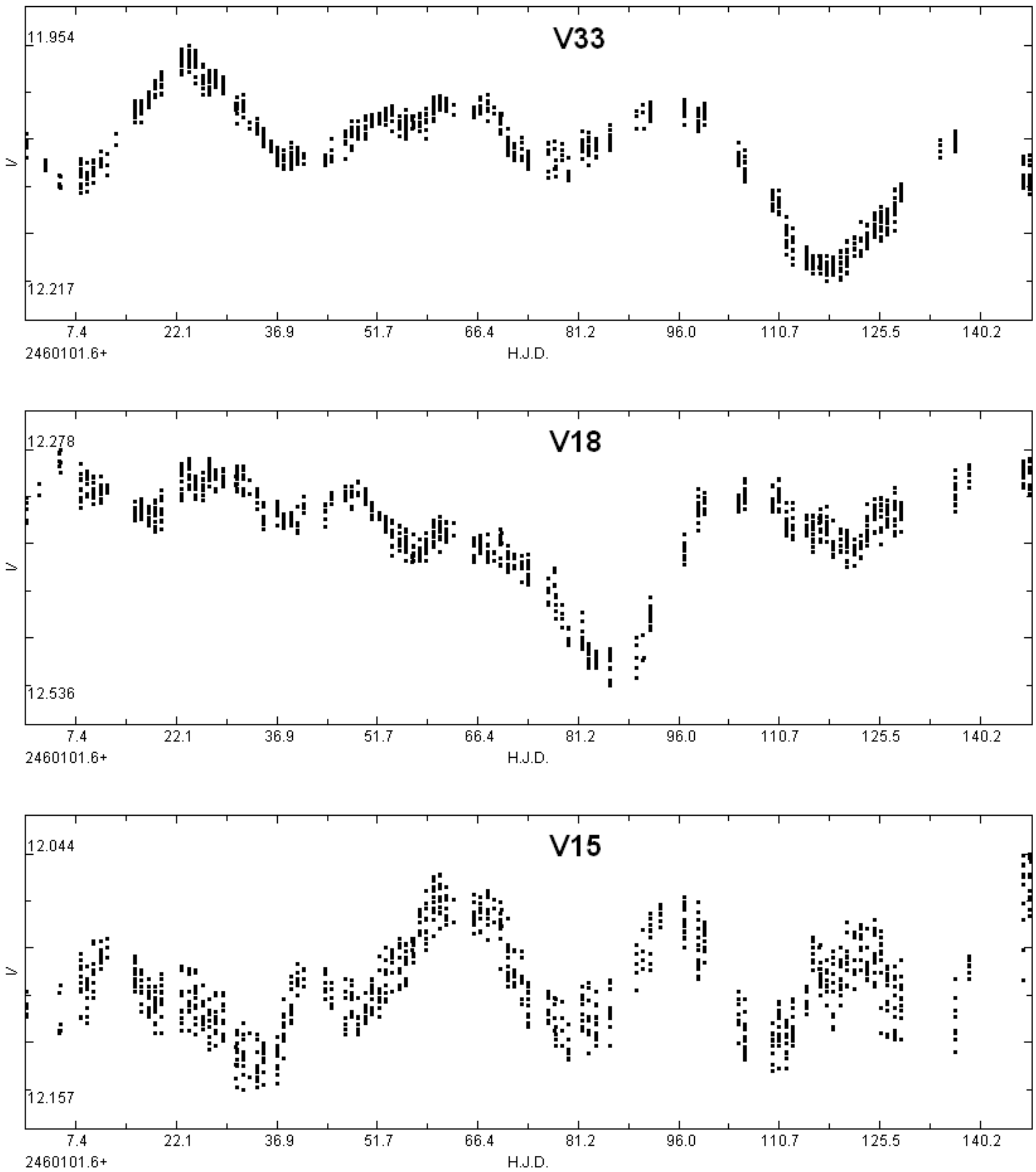

Figure 2: Light curves of the variable stars V33 (upper panel), V18 (central panel) and V15 (lower panel) obtained throughout the 2023 photometric campaign: all the stars are semiregular red giants. Our equipment has allowed us to capture very small oscillations (or micro changes) represented in each panel.

2 Candidates: Identification, magnitudes *BV* and variability

After analyzing the positions listed by DER19 in their Table 3 we have identified the candidates for their Ludendorff number, which has allowed us to locate their magnitudes and other interest parameters in SIMBAD: Stetson *et al*. (2019, hereafter STE19) include in their paper these four stars and tabulate their magnitudes *B*, *V* and Variability Index V.I. (the probability of being variable), that we show in Table 1:

Table 1: Candidates
Magnitudes *B*, *V* and Variability Index

Star	Name	*B* [mag]	*V* [mag]	V.I.
C1	L198	14.095	12.948	1.313
C2	L252	13.868	12.642	1.204
C4	L262	13.852	12.250	4.105
C5	L296	13.719	12.545	2.607

In Table 2 we show the positions of these stars (from Gaia DR3):

Table 2: Astrometry

Star	RA [h:m:s]	DEC [º ' "]
C1	16:41:32.33	+36:27:34.52
C2	16:41:34.33	+36:30:13.03
C4	16:41:34.80	+36:27:19.38
C5	16:41:35.68	+36:26:48.61

When reviewing the tabulated data we verify that two of them (C4 and C5) are bright stars located near the top of the Red Giants Branch, such as the remaining red variables, which could suggest some variability. By consulting the Variability Index we verify that these are high (greater than 2.50, a clear sign of variability) which confirms our supposition; according to these data, the other two stars show only slight indications of variability (C1 and C2). C4 has a value similar to that of the variable V18 (4.568) but higher than V11 (3.394) or V20

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(3.217) according to STE19; C5, for its part, has a value similar to that of V33 (2.410) or V38 (2.313). The Variability Index of C1 and C2 is similar to that of the variable V64 (1.260), but also like that of Candidate C12 (1.253), the brightest *blue straggler* in the cluster whose variability we will show in detail in a future paper. Other variables also show very low values, as in the case of V15 (0.885), V40 (0.860), or V32 (0.734) according to STE19.

3 Photometry. Observations and data reductions

We obtained *V*-band photometry during a 2023 campaign from Cáceres (Spain), carried out between June and October. Since the spring of 2019 we have studied carefully the variable and suspected variable stars of Messier 13: we employed the 0.2-m telescope f/10 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: all cluster frames were calibrated using bias and flat field frames through standard procedures; bias and twilight flats were taken every observing night. The image data were obtained during several runs where we collected a total of 944 frames through Johnson *V* filter; Table 3 shows a detailed log of the observations: the exposure times were 120 s; on most nights the weather was very good and the seeing varied over a rather wide range, between 1.5 and 3.5 arcsec, with a typical value of 2.5-3.0 arcsec. The CCD camera is an ATIK 414EX, of 1391 × 1039 pixels (squares, 6.5 microns), with a scale of 0.68”/pixel and a field of view of 15.9 × 11.8 arcmin^2 (Figure 1). We have also observed other variable stars in the cluster, obtaining light curves and determining periods and amplitudes: Figure 2 is a good example.

Table 3: Observational log

Year	H.J.D. Start	H.J.D. End	Nights	Images
2023	2460101.649	2460249.270	149	944

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 published in the photometric study by STE19. The CCD finder chart (with labelled stars) is shown in Figure 1: the magnitudes were determined relative to L158, L1073 and L848, whose constancy during the run was confirmed using L244, L353, and L777. Table 4 presents the coordinates (J2000) of the comparison and check stars taken from SIMBAD and their *V* magnitudes and *B* – *V* colour index from STE19.

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

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Table 4: Comparison and check stars

Star	ID	RA (J2000) [h:m:s]	DEC (J2000) [° ' "]	*V* [mag]	*B* – *V* [mag]
L244	2MASS J16413437+3625048	16:41:34.36	+36:25:04.76	12.602	1.225
L158	2MASS J16413053+3629434	16:41:30.52	+36:29:43.44	12.675	1.144
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
L777	2MASS J16414547+3629586	16:41:45.46	+36:29:58.53	12.864	1.145
L848	2MASS J16414739+3625111	16:41:47.40	+36:25:11.13	13.110	1.071

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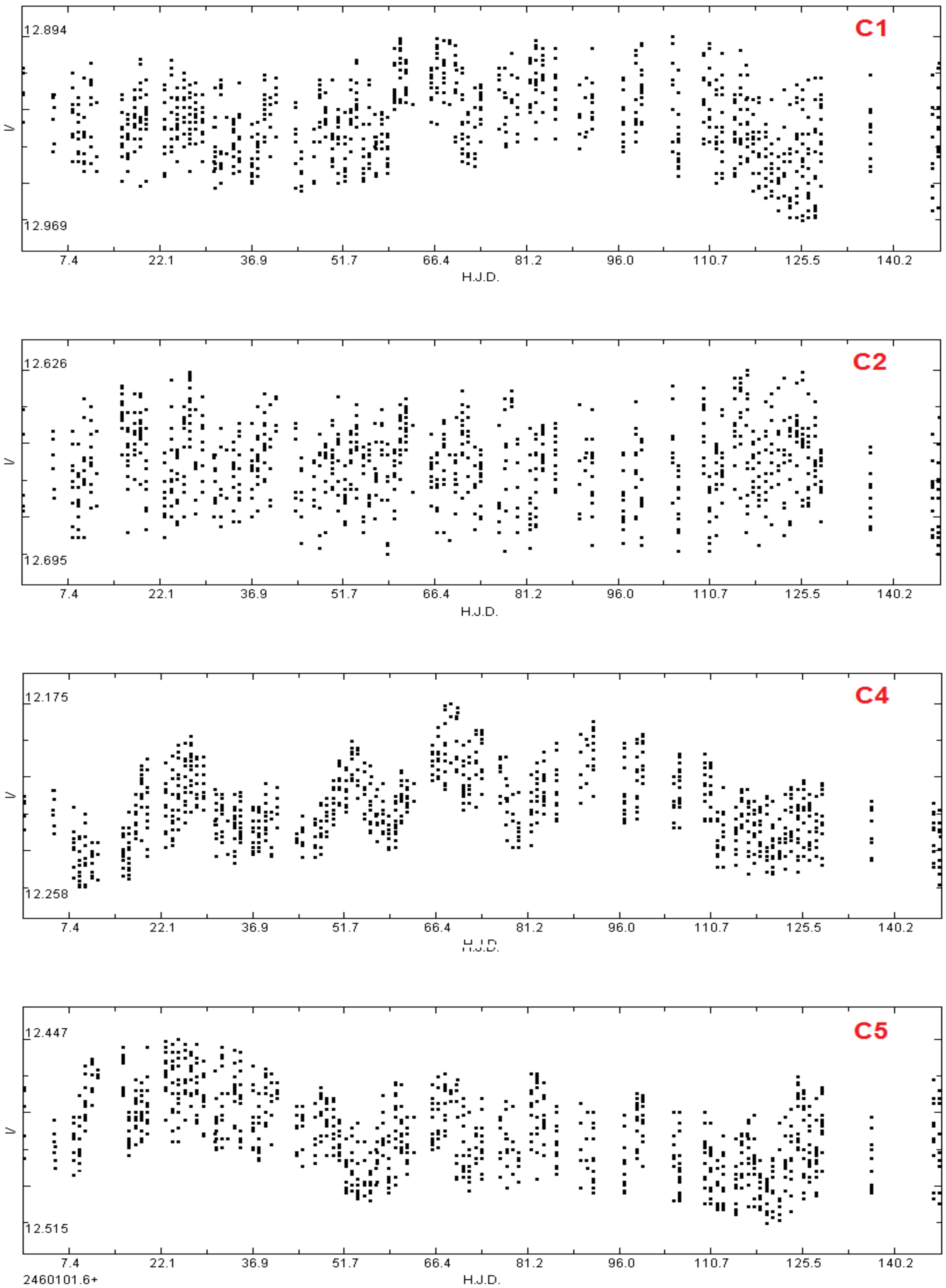

Figure 3: Light curves of the four Candidates obtained throughout the 2023 photometric campaign.

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This calibration procedure with three stars works perfectly: in Figure 2 we present the light curves of the variable stars V33 (upper panel), V18 (central panel), and V15 (lower panel) throughout the 2023 campaign; in both, we can see the behavior of this stars over the weeks, and are coherent without showing any strange or unexpected effect. All the frames were captured starting at the same zenith height each night, which minimized errors due to the atmosphere.

Our photometry is very precise and allows us to detect oscillations of a few hundredths of a magnitude in these light curves. This data set covers HJD 2460101.649 to HJD 2460249.270 with images obtained on 149 nights. Figure 3 shows the light curves obtained: that is, the behavior of each candidate. Only in the case of C2 the oscillations are so small that it is barely appreciated variation. A careful examination of light curves shows that C1 is a slow variable (P ~100 days), C4 presents at least two periods while C5 is also a slow variable; in the case of C2 it is not easy to know what its period is without obtaining the periodogram.

Table 5 shows the average V magnitudes, measured amplitude, variation range V, and its absolute magnitudes M_V using $(V - M_V) = 14.33$ and $E(B - V) = 0.02$ (Harris, 2010):

Table 5: Average V magnitudes, amplitudes, range V and M_V

Star	V [mag]	Amplitude [mag]	Range V [mag]	M_V
C1	12.929 ± 0.016	0.075	12.894-12.969	–1.40
C2	12.662 ± 0.014	0.069	12.626-12.695	–1.67
C4	12.222 ± 0.016	0.083	12.175-12.258	–2.11
C5	12.482 ± 0.015	0.068	12.447-12.515	–1.85

Using the average magnitudes just obtained, and the $B - V$ color index tabulated by STE19, we have determined its position in the color-magnitude diagram (Figure 4) taken from the paper of Arp and Johnson (1955): C4 and C5 lie at the top of the red giant branch, very close to the tip, next to the brightest variables of the cluster (V11, V42, V39, V24, V17, etc.) whose absolute magnitudes (from Osborn *et al.*, 2017, hereafter OSB17) are between $M_V = -2.42$ (V11) and $M_V = -1.89$ (V43); C2 and C1 appear a little lower with absolute magnitudes similar to those of V45 ($M_V = -1.74$) and something greater than V41 ($M_V = -1.19$), according to this paper.

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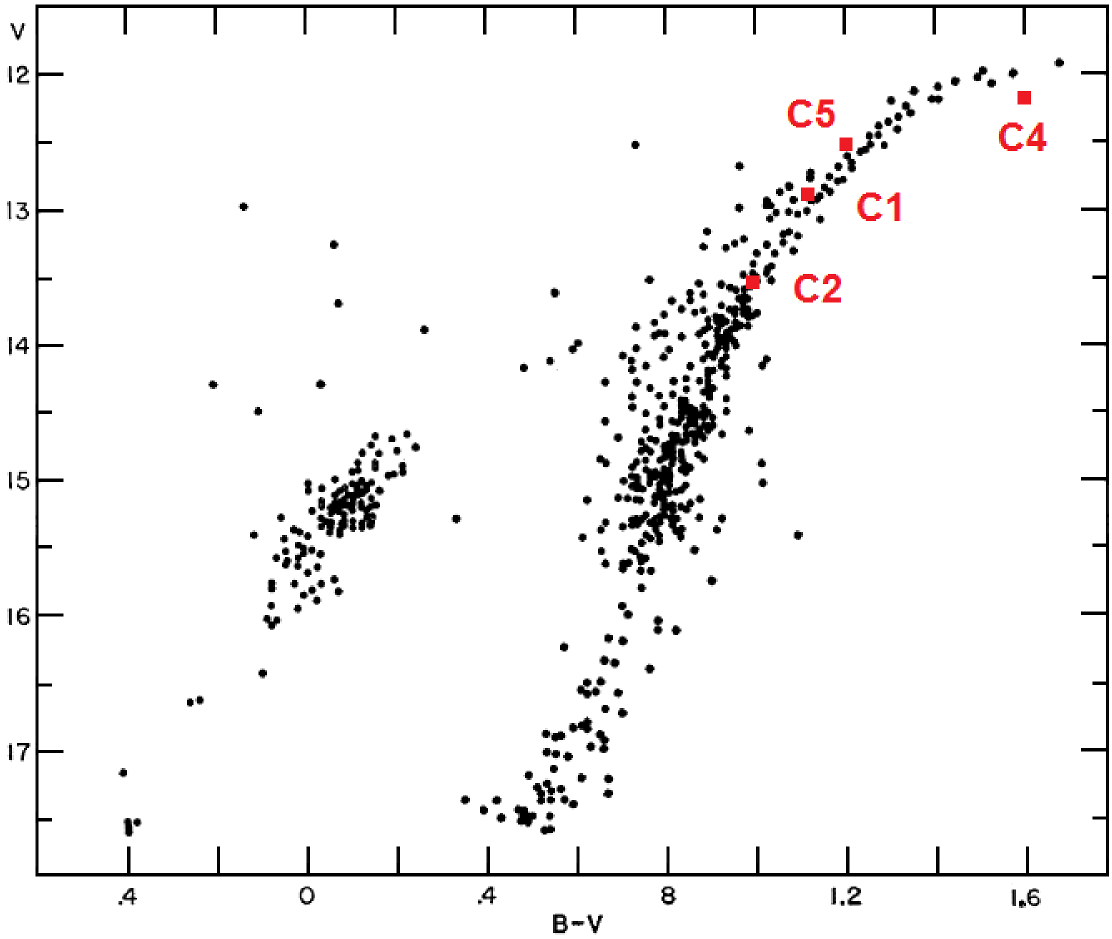

Figure 4: Color-Magnitude diagram obtained by Arp and Johnson (1955): in it we have marked the position of C1, C2, C4 and C5 in the Red Giants Branch.

4 Data analysis

The analysis of the 944 points of each of the candidates has been carried out with *A.V.E.* (*Análisis de Variabilidad Estelar*), from the “Grupo de Estudios Astronómicos GEA”, using the Scargle Algorithm (Scargle, 1982). In Figure 5 we show the periodograms obtained for each variable: to better represent these periods, the drawn intervals range between 150 days (in the case of C1 and C4) and the 90-95 days for C5 and C1 respectively. In the case of C4 the most important period (140.56 days) seems to coincide with the duration of the campaign (149 days), however, in Section 5 we will verify that a similar period (159.90 days) is obtained from ASAS-SN measurements. Table 6 shows the periods obtained for each of the variables.

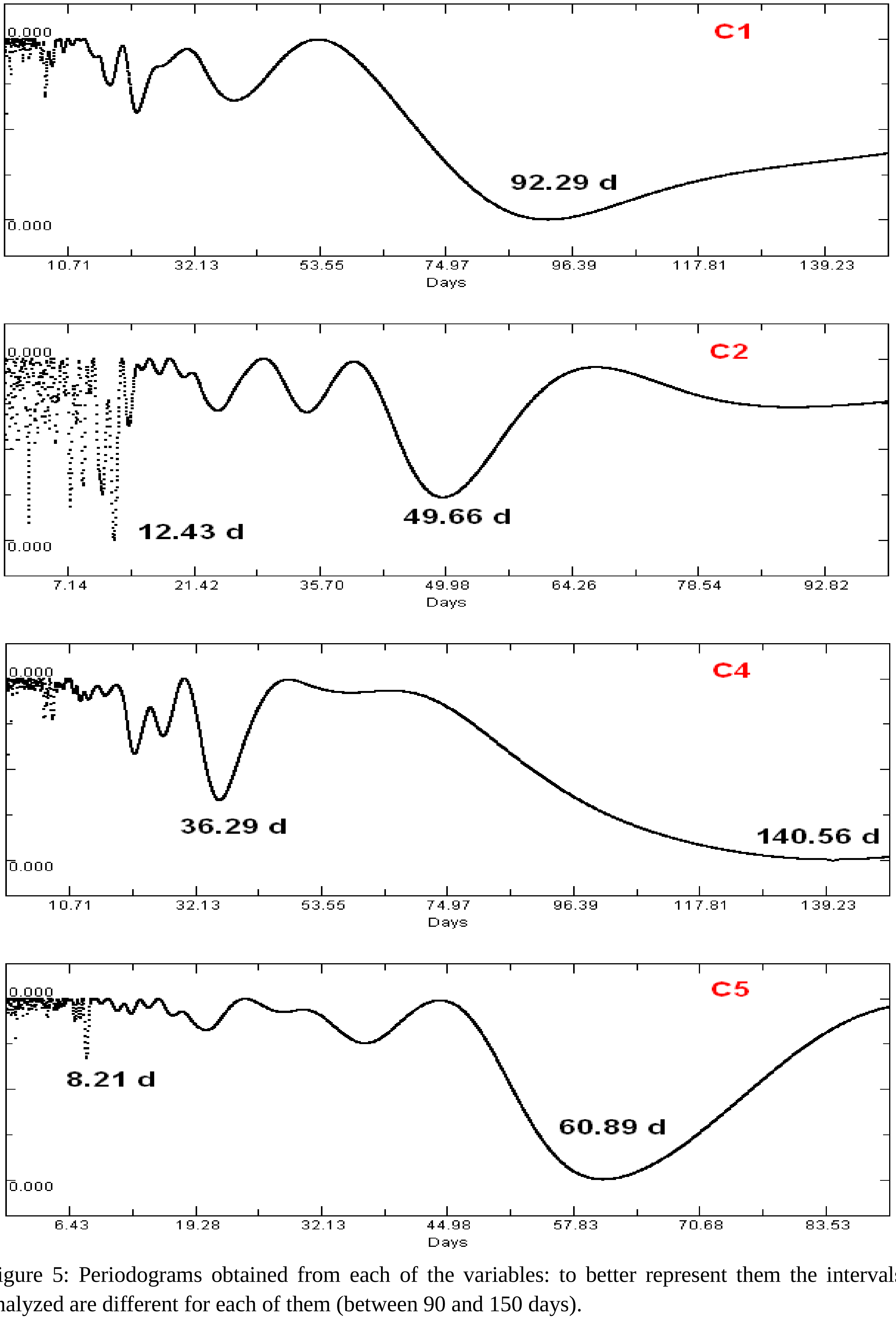

Figure 5: Periodograms obtained from each of the variables: to better represent them the intervals analyzed are different for each of them (between 90 and 150 days).

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
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Table 6: Periods of the Candidates

Star	Points	P1	P2	P3	P4
C1	944	92.29	22.48	39.06	6.95
C2	944	12.43	7.45	11.01	49.66
C4	944	140.56	36.29	21.82	26.70
C5	944	60.89	8.21	36.62	20.42

We will proceed to discuss each new variable using the information contained in the different papers and catalogs available in SIMBAD and VizieR.

C1 (L198 = TIC 57158435 = Gaia DR3 1328058038875633408). This star, whose effective temperature is 4575 K with a radius equal to 23.17 times the solar (Stassun *et al*., 2019), appears in the *ZTF catalog of periodic variable stars* (Chen *et al.*, 2020) with a period equal to 114.919 days, this a little greater than P1 that determined by us. In the paper *15000 ellipsoidal binary candidates in TESS* (Green *et al*., 2023) this star is identified as a binary system with an orbital period equal to 5.145815 days, similar to P4 obtained by us. However, we cannot draw a coherent light curve. By contrast, when using our data (92.29 days) we can draw a good light curve (Figure 6): this value is practically identical to the period of the brilliant variable V11 (92.0 days, a SRb star) and indicates, in our opinion, pulsation in the fundamental (F0) mode.

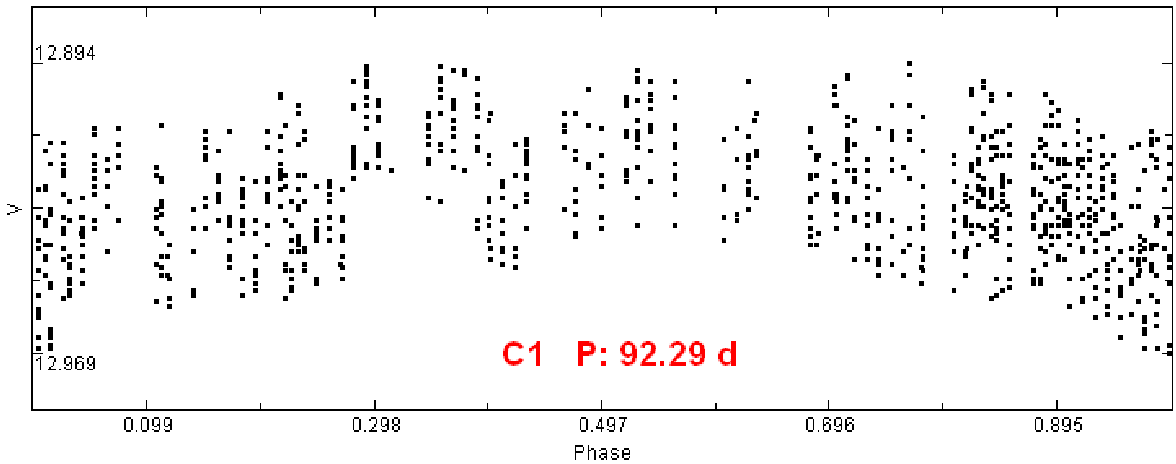

Figure 6: Light curve of C1, in phase, drawn with a period equal to 92.29 days.

August 2024 https://oejv.physics.muni.cz ISSN 1801-5964
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C2 (L252 = TIC 57162516 = Gaia DR3 1328058279393978880). This star, whose effective temperature is equal to 4210 K with a radius equal to 54.2 times the sun's (Meszaros *et al.*, 2009) or 4405 K and 33.36 times the sun's (Stassun *et al.*, 2019), appears in the *15000 ellipsoidal binary candidates in TESS* with an orbital period equal to 8.982240 days, similar to P2 obtained by us, with which a good quality light curve is obtained (Figure 7, upper panel): when analyzing our data we found a weak signal, at 8.902605 days, that results in a light curve of reasonable quality (Figure 7, lower panel).

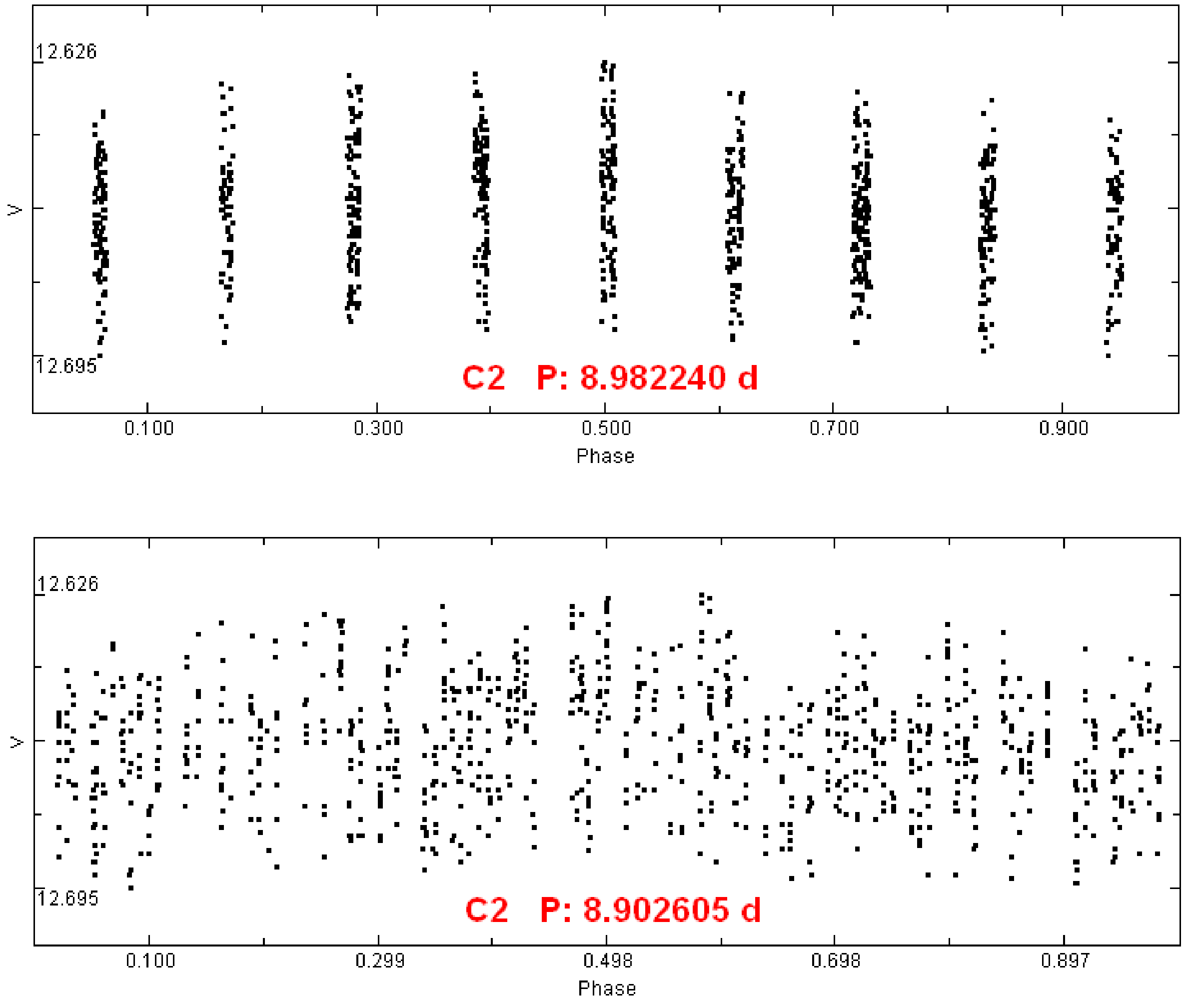

Figure 7: Light curves of C2, in phase, drawn with a period equal to 8.982241 days (upper panel) and 8.902605 days (lower panel).

C4 (L262 = TIC 57188171 = Gaia DR3 1328057871377511808). This brilliant star, whose effective temperature is 4346 K with a radius equal to 60.70 times the solar (Yu *et al.*, 2023), also appears in the *15000 ellipsoidal binary candidates in TESS* with an orbital period equal to 8.314747 days. However, with this value we do not draw a coherent light curve. Analyzing our data very carefully we find a signal, with a period equal to 7.93 days, with which a light curve of moderate quality is obtained (Figure 8, upper panel).

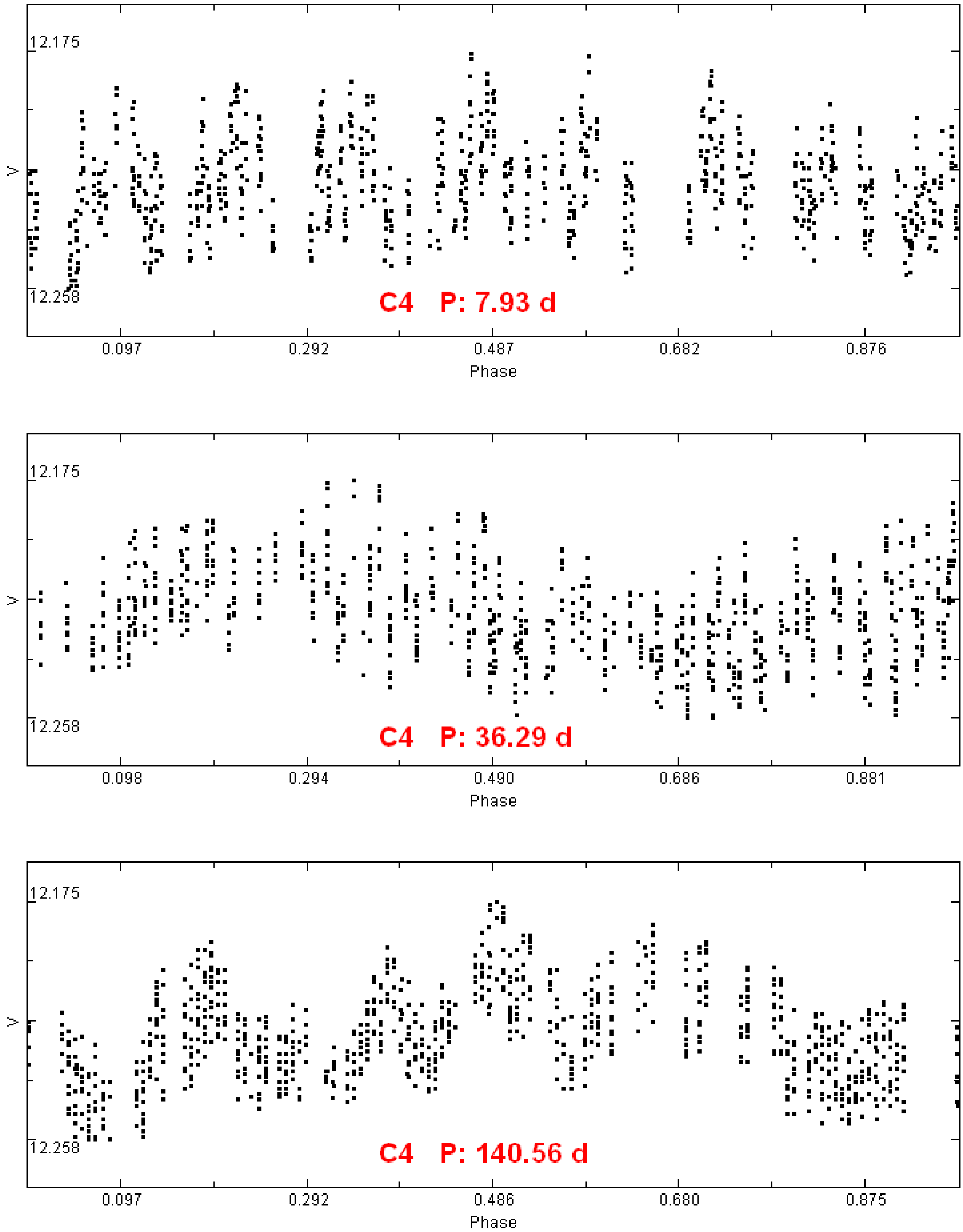

Figure 8: Light curves of C4, in phase, drawn with a period equal to 7.93 days (upper panel), 36.29 days (central panel) and 140.56 days (lower panel). This variable is probably multiperiodic.

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A better quality result is obtained with the second period (P2: 36.29 days), which we show in Figure 8 (central panel), but we cannot ignore the most prominent period (P1 = 140.56 days, which may be a long secondary period?) with which a good light curve is also obtained (Figure 8, lower panel) in which the influence of at least a second shorter period is observed. With these results, and without forgetting their behavior throughout the campaign (Figure 3) we can say, without a doubt, that it has at least two different periods like other brilliant variables of the cluster (OSB17). We can estimate its absolute magnitude $M_V = -2.11$, not very different from what these authors find for V15 (type SR and $M_V = -2.21$) although higher than that of V18 (type L and $M_V = -2.01$). The analysis of the photometric data obtained by ASAS-SN, which we will analyze below, suggests a long period (~140 days).

C5 (L296 = TIC 57188311 = Gaia DR3 1328057832717224192). This star, whose effective temperature is 4485 K with a radius 36.22 times the sun's (Paegert *et al.*, 2021), also appears in the *15000 ellipsoidal binary candidates in TESS* with an orbital period of 3.767987 days. However, when we draw the light curve in phase with this value we do not obtain any results. By contrast, when using P = 60.89 days (P1 in Table 6) a light curve of fairly good quality is obtained (Figure 9); this value is similar to the one tabulated in the CVSGC (Clement, 2017) for variable V39 (56.0 days). Its absolute magnitude $M_V = -1.85$ is similar to that OSB17 determined for V43 (type L and $M_V = -1.89$).

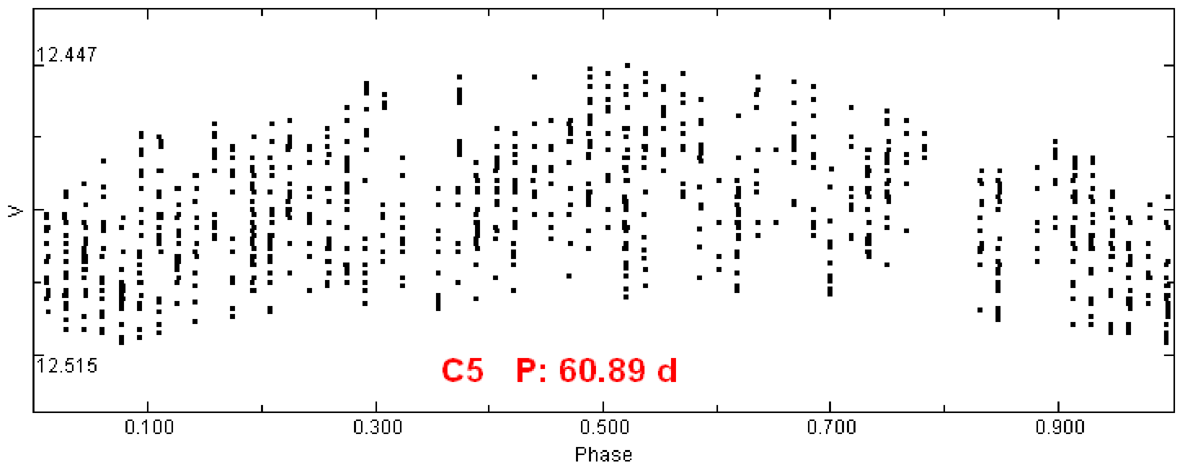

Figure 9: Light curve of C5, in phase, drawn with a period equal to 60.89 days: the maximum and its shape appears very well represented.

5 ASAS-SN photometry (2019-2023)

To confirm these results we used ASAS-SN data (Jayasinghe, T. *et al*., 2018; Shappee, B. J. *et al*., 2014; Kochanek *et al*., 2017), in SLOAN-g band, of each of the four variable stars between 2019 January and 2023 December (Figure 10): 3405 for C1, 3462 for C2, 3418 for C4 and 3340 for C5. We eliminated some discordant measurements having a very low signal-to-noise ratio. The campaigns extended between 250 and 310 days, depending on the local meteorological condition and telescopes used, because ASAS-SN is a set of 24 robotic telescopes (whose diameter is 14 cm) distributed around the globe: Ohio and Texas in the United States, Chile, South Africa, and China.

The search for the period was carried out in the same way as that used with our measurements in the interval 1-250 days but, to better appreciate and represent the most notorious periods (sometimes several, both long and short), have been represented in shorter intervals.

6 Discussion

The visual examination of the light curves, not in phase, shows a very slight variability in the case of C1 with long-period oscillations (for example in the 2021 campaign). In the case of C2 its variability is not evident because it is very small: we cannot deduce the period from the data without obtaining the periodogram. However, in the case of C4 and C5 we see campaigns in which very obvious light variations are observed: 2020, 2021, and 2023 in the case of C4, and 2020, 2022 and 2023 for C5. For C4 we have represented the light curves of the five campaigns (Figure 10): in them, we can verify not only that their oscillations last more than one hundred and fifty days but, in the years 2020 and 2022, small modulations are apparent of shorter duration that appear as "arches". C5 is a long-period variable whose oscillations are seen in the 2020 and 2022 campaigns but not in the remaining ones: when we analyze, one by one, each campaign will verify that its period ranges from year to year but in all cases it ranges between 75 and 89 days, being therefore similar to that obtained from our data. We present below the behavior of each of the new variables.

C1: The period obtained (92.65 days, Figure 11, upper panel) is almost identical to that obtained from our data (92.29 days), confirming our conclusions: in fact the light curve obtained in phase is quite good (Figure 11, upper panel), despite the slightest precision of these measurements and the largest dispersion. The light curve of DER19 (Figure 14 of their paper), although incomplete, also confirms this behavior. Mean magnitude: 12.306 ± 0.033 g.

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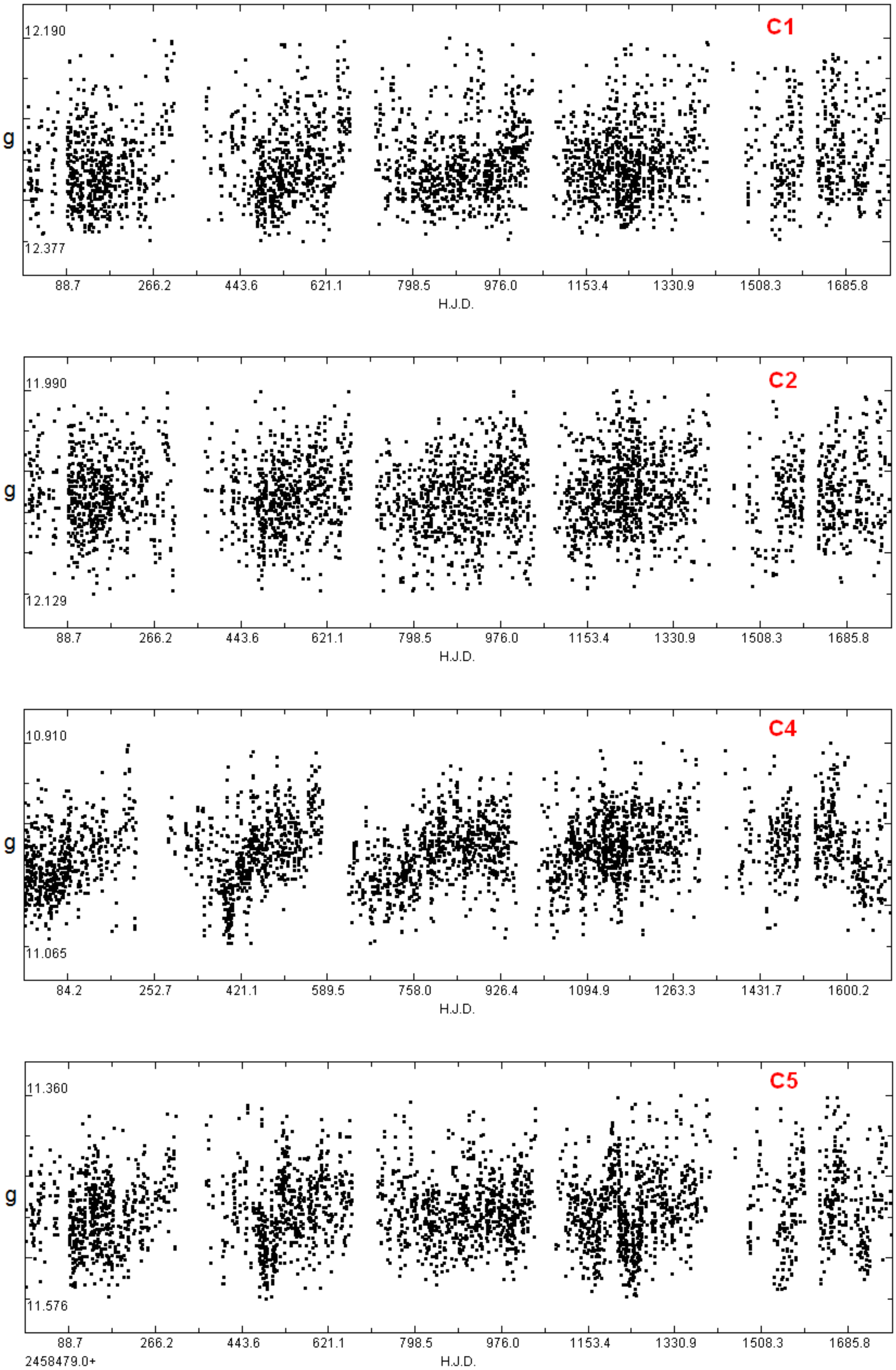

Figure 10: Light curves of the four variables of the years 2019 (left) to 2023 (right) in SLOAN-g band.

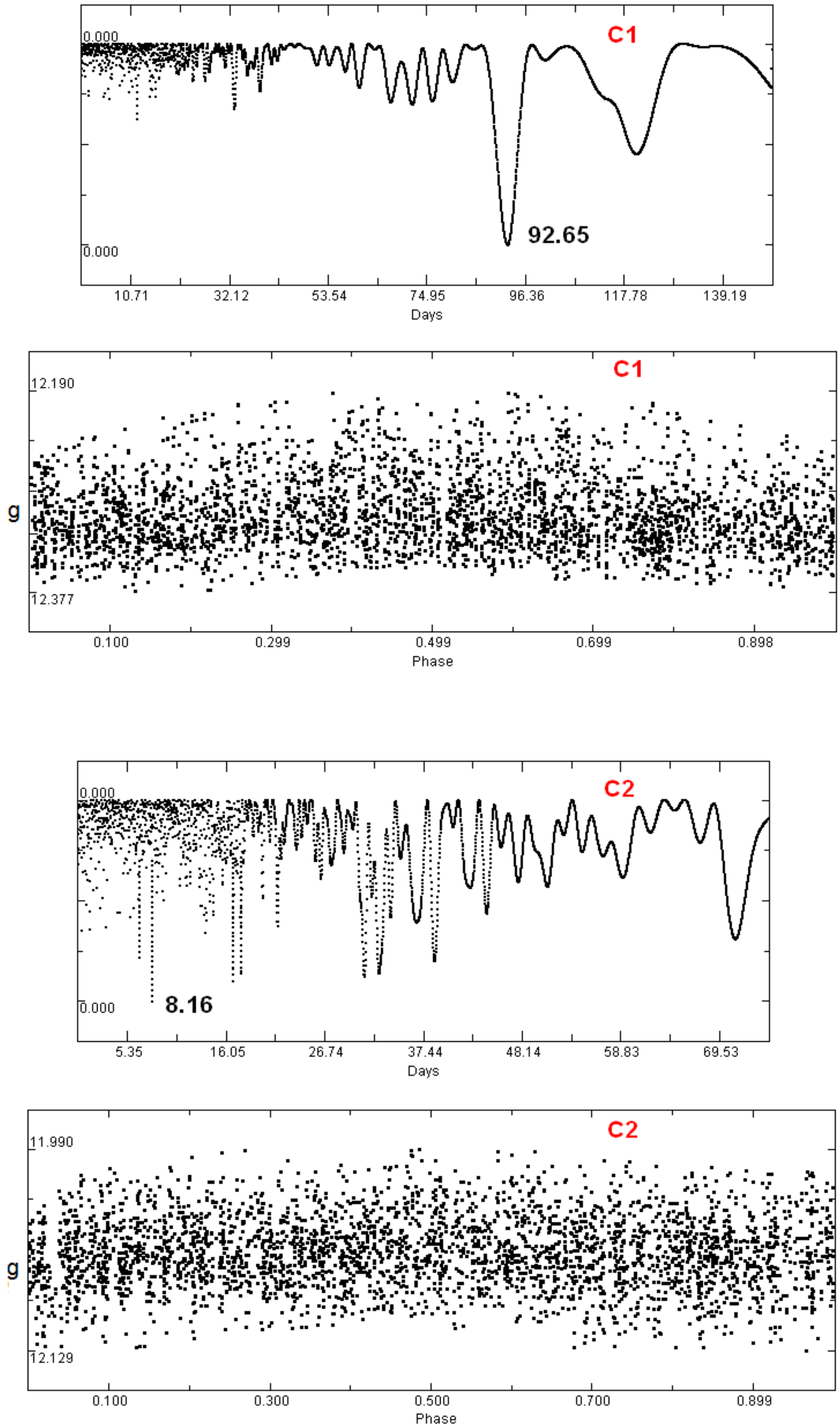

Figure 11: Periodogram of variable C1 and light curve, in phase, drawn with a period equal to 92.65 days (upper panel) and periodogram of variable C2 and light curve, in phase, drawn with a period equal to 8.16 days (lower panel).

OPEN EUROPEAN JOURNAL ON VARIABLE STARS
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C2: Although several short or medium periods can be seen in the periodogram (Figure 11, lower panel) the most notable, 8.16 days, is very similar to that obtained from our data (8.90 days); with it we have drawn its light curve, in phase, which we show in Figure 11, lower panel. Being very close to V59, these measurements are slightly contaminated by its glare: that is why it apparently appears brighter (12.061 ± 0.025 g) from that obtained from our measurements: 12.662 ± 0.014 *V*.

C4: This variable is located not far from other bright variables, such as V42, in a zone of stellar crowding, so the measurements are contaminated by scattered light; the average magnitude obtained from these data (10.994 ± 0.025 g) differs something more than a magnitude of that measured by us: 12.222 ± 0.016 *V*. The analysis of the combined measurements of the five campaigns (Figure 12, upper panel) shows a very marked period equal to 159.90 days with which a fairly quality light curve is obtained (Figure 12, lower panel). However, the periodogram suggests four other slightly shorter and longer periods, without ignoring a short period (36.12 days) not very different from those obtained by us (36.29 days) with which a good light curve is obtained. If we represent the five photometric campaigns one by one (Figure 13), we will see that in each of them, the star has varied in brightness with a similar –but different– period from year to year.

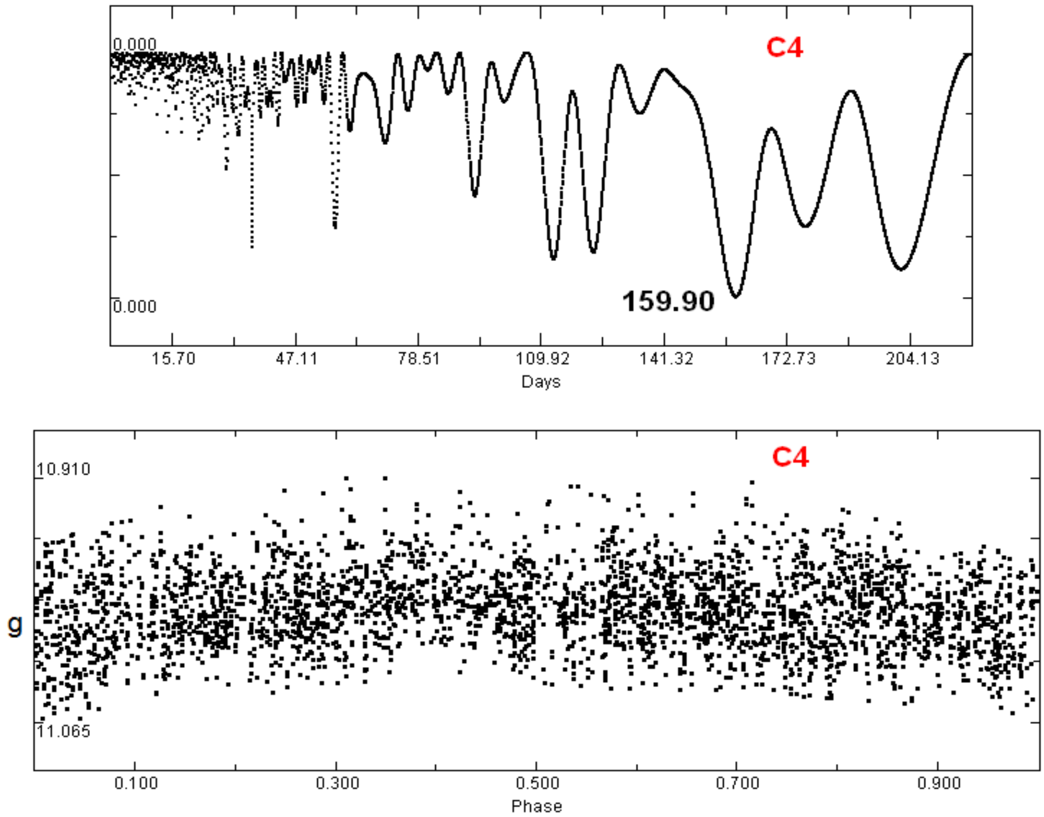

Figure 12: Periodogram of variable C4 (upper panel) and light curve, in phase, drawn with a period equal to 92.65 days (lower panel).

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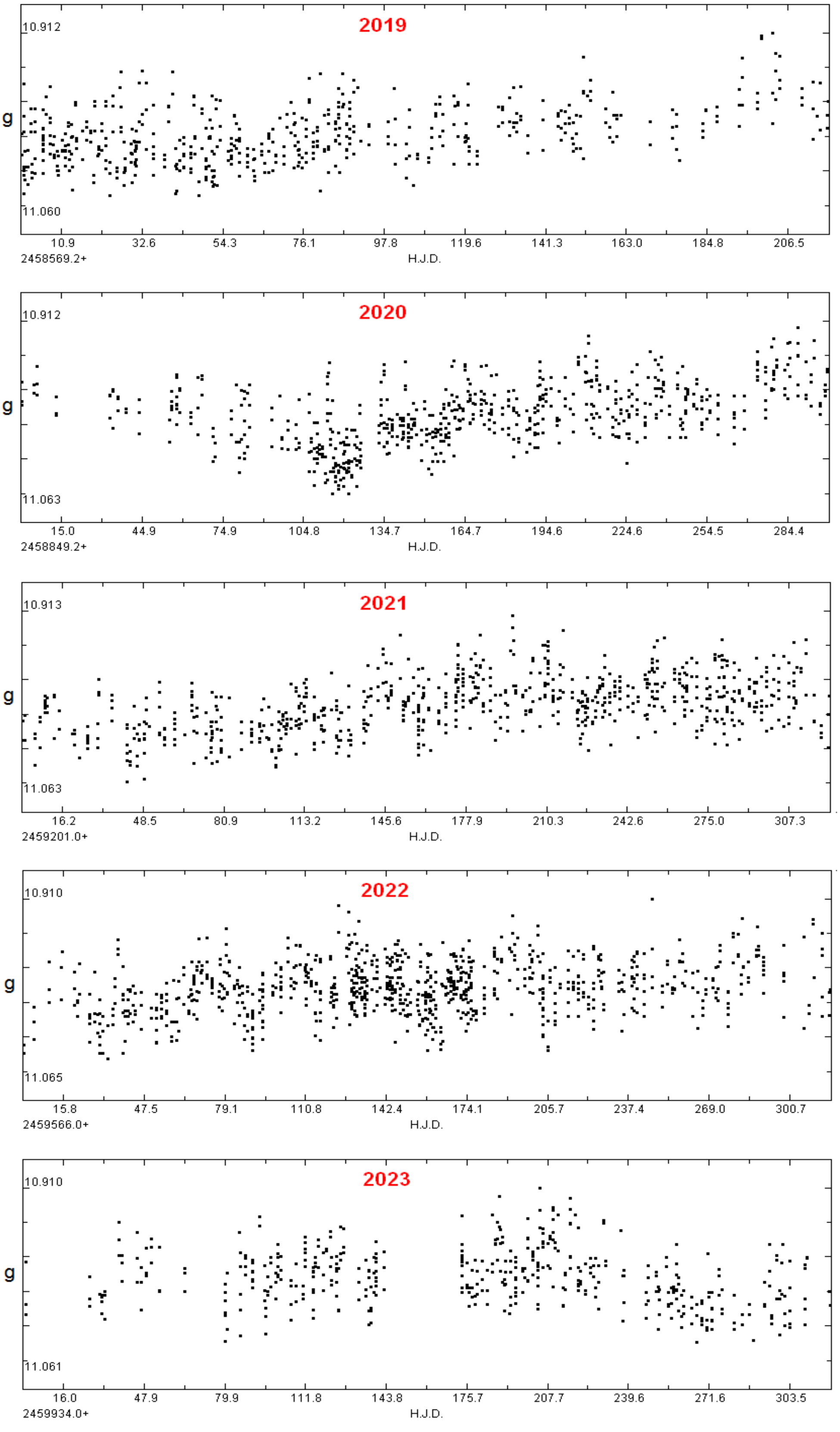

Figure 13: C4 light curves drawn over five different campaigns between 2019 (upper panel) and 2023 (lower panel).

Periodograms offer the following periods: 2019 = 57.2 days; 2020 = 37.0 and 115.0 days; 2021 = 28.2 and 104.5 days; 2022 = 30.0 and 56.7 days, and finally 2023 = 39.8 and 133.7 days. When the short period is more intense, noticeable "arcs" appear in the light curves as in the 2020 and 2022 campaigns. The data suggest the existence of two very different periods: the first is short (between 28 and 39 days, 36.29 days according to our photometry) while the second is long but of varying duration: between 104 and 134 days in the five campaigns analyzed, 140.56 days according to our 2023 photometry. In fact, in this last campaign, the two most notable periods recorded by us (36.29 and 140.56 days) are practically identical to those determined from the ASAS-SN measurements: 39.8 and 133.7 days respectively. The data suggest that this variable has a second long period such as V19 (168 days), V40 (170 days), or V18 (200 days) according to OSB17 (Table 8 in their paper).

C5: This variable is located not far from other bright variables, such as V11, in a zone of stellar crowding: the average magnitude obtained from these data (11.483 ± 0.038 g) differs one magnitude of that measured by us: 12.482 ± 0.015 *V*. The analysis of the combined measurements of the five campaigns (Figure 14, upper panel) shows a very marked period equal to 95.08 days with which a good light curve is obtained (Figure 14, lower panel).

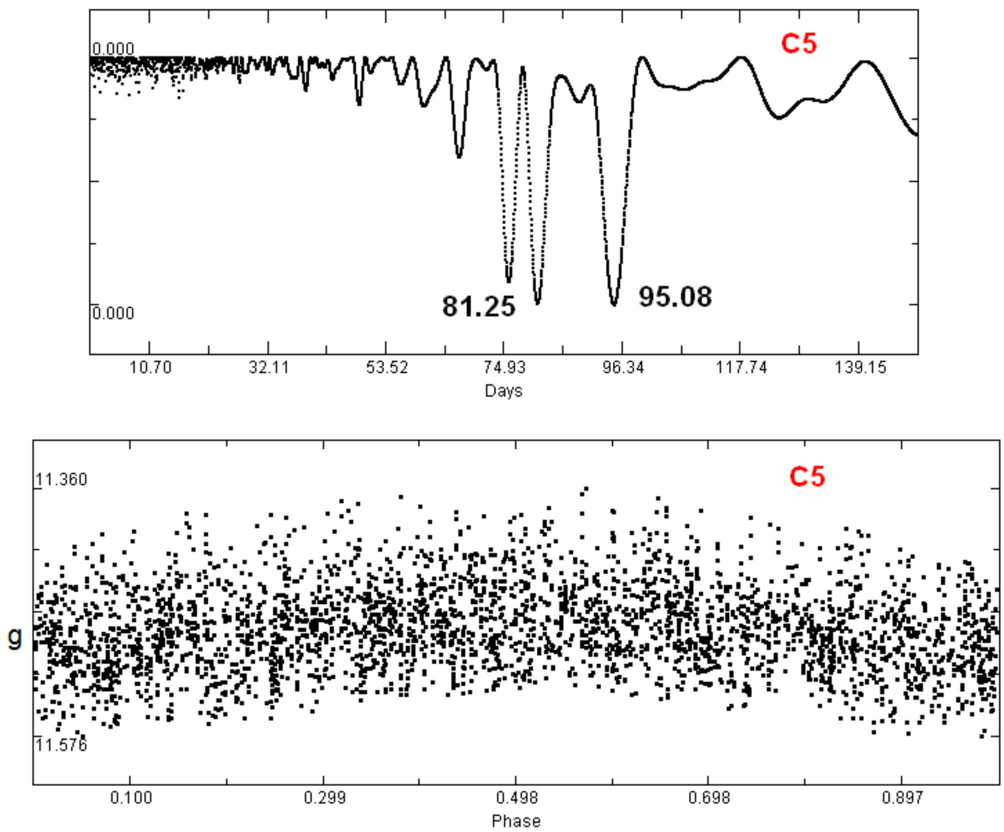

Figure 14: Periodogram of variable C5 (upper panel) and light curve, in phase, drawn with a period equal to 95.08 days (lower panel).

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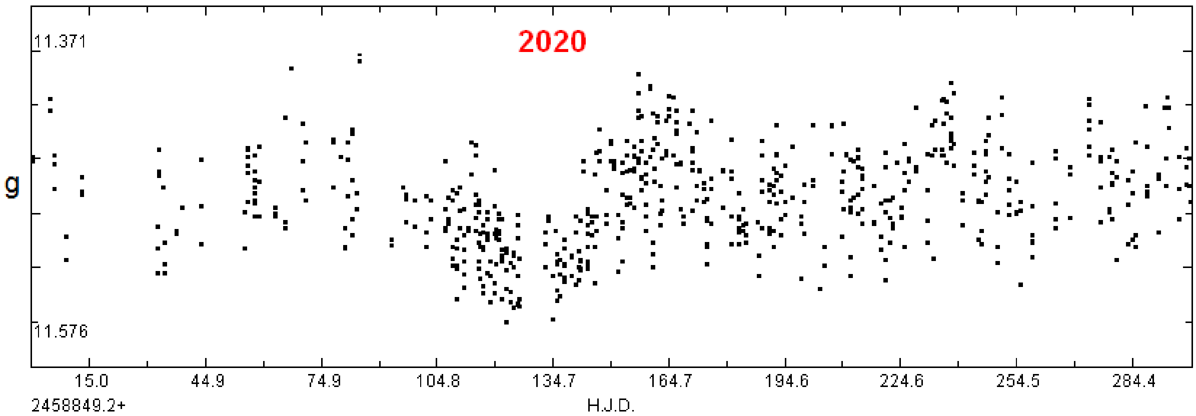
However, we cannot ignore that three shorter periods appear: 81.25 days, 76.03 days, and 67.03 days (the least prominent), of similar duration to our photometry (60.89 days). When we analyze the photometric data in each year's campaign we get a very different result: 2019 = 78.9 days, 2020 = 74.8 days, 2021 = 77.7 days, 2022 = 89.2 days, and 2023 = 80.9 days. This result suggests that the period, at least in the 2019-2023 interval, ranged between 75 and 89 days (or 82 ± 7 days). This phenomenon is apparent in the campaigns 2020 and 2022 (Figure 15), in which we see significant oscillations of 75 and 89 days respectively, similar to that of the brilliant variable V11 (P = 92.0 days) whose absolute magnitude is equal to −2.42 (OSB17), although of our photometry we find its absolute magnitude equal to $M_V = -1.85$.



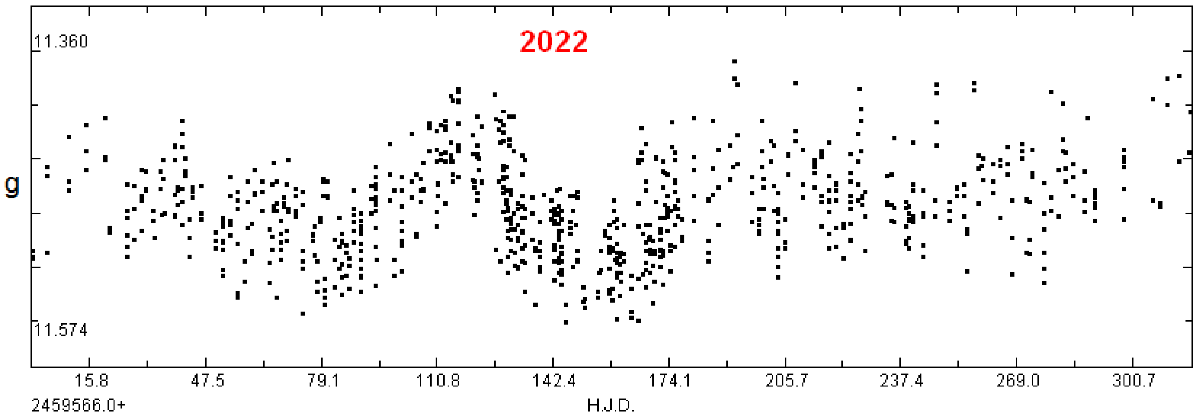


Figure 15: C5 light curves of the 2020 and 2022 years: in both the star presented important and outstanding light oscillations.

Variability and radial velocities. We can also appreciate signs of variability using the paper of Lupton *et al*. (1987), in which they measure radial velocities of 147 stars of the cluster, and estimate the probability of being variable by analyzing the value of the chi-

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squared test (χ^2): only in one of them (C2) this value is high (χ^2 = 9.24, with only two different velocities) being similar to that of the star L240 (χ^2 = 10.89, with five velocities) for which they suggest variability: now this star is V58. The values for the remaining three stars are C1 (none, they measured only one velocity), C4 (χ^2 = 0.41, two velocities), and C5 (χ^2 = 0.10, two velocities). They suggested variability for the star L261 (χ^2 = 3.40 with two velocities), now V64, but the variability of L687 (χ^2 = 17.46, four velocities) can also be intuited with these values: now this star is V62.

7 Conclusions

Using filtered CCD images obtained in 2023 we have verified that the Deras's candidates C1, C2, C4 and C5 are variables, although their periods are very dissimilar: 92.29 days for C1, 8.902 in the case of C2, 140.56 days for C4 and 60.89 in the case of C5. The periodograms show the existence of at least a second shorter period that modifies and modulates the light curves, modulation very visible in the curve (original, not in phase) of C4. Using the definitions in the *General Catalogue of Variable Stars*, we classified the stars C1, C4, and C5 as SRb: SRb indicates those stars showing both fairly persistent periods and evidence of interacting short (not LSP) periods. C2 is probably an ellipsoidal variable (type ELL in the *General Catalogue of Variable Stars*: these are close binary systems with ellipsoidal components but showing no eclipses; light amplitudes do not exceed 0.1 mag in *V*). We have calculated its absolute magnitudes: C4 is among the brightest variables with $M_V = -2.11$, a value similar to other bright variables of the cluster; the values of the remaining stars range between $M_V = -1.85$ for C5 and $M_V = -1.40$ for C1. We measure changes in their magnitude, of very small amplitude (0.068 mag for C5 to 0.083 mag for C4), consistent with the results announced by its discoverers: >0.04 mag for C1 and >0.07 mag for the remaining ones. Using the average magnitudes obtained from our photometry we have determined its position in the color-magnitude diagram: C4 and C5 are bright stars located at the top of the red giant branch, next to the brightest variables of the cluster, while C2 and C1 appear a little lower. We have analyzed the photometric measurements obtained by ASAS-SN between 2019 and 2023, in SLOAN-g band, calculated their periods, and drawn its light curves in phase: in general, their periods are similar or very similar to ours from the year 2023. The photometric measurements obtained for us in previous campaigns (2019, 2020 and 2021), together with those we have shown here, suggest that the most luminous stars of cluster (between magnitudes 11.95 and 12.55 *V*) are all variables −many of them are multi periodic−, some of them of very small amplitude not previously identified as such (as V63 or V64): we will present new variables and their parameters (amplitudes and ranges *V*, periods and light curves) in a future paper. Since the last variable star recorded in the *CVSGC* is V65 (Violat-Bordonau, 2024) we propose for them the names of V66, V67, V68, and V69.

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References

Arp, H. C., Johnson, H. L, 1955, ApJ, 122, 171: 1955ApJ...122..171A
Astroart, MSB Software: *ASTROART*
AVE, Análisis de Variabilidad Estelar, G.E.A: *AVE Análisis de Variabilidad*
Chen, X. *et al*., 2020, ApJS, 249, 18: 2020ApJS..249...18C
Clement, C. M., 2017, VizieR On-line Data Catalog, V/150: NGC 6205 (Messier 13)
Deras, D. *et al*., 2019, MNRAS, 486, 2791: 2019MNRAS.486.2791D
FotoDif, Fotometría Diferencial, Julio Castellano: *FotoDif*
General Catalogue of Variable Stars: http://www.sai.msu.su/gcvs/gcvs/vartype.htm
Green, M. J. *et al.*, 2023, MNRAS, 522, 29: 2023MNRAS.522...29G
Harris, W. E., 2010: 2010arXiv1012.3224H
Jayasinghe, T. *et al*., 2018, MNRAS, 486, 1907: 2019MNRAS.486.1907J
Kochaneck *et al.*, 2017, PASP, 129, 980, 104502: 2017PASP..129j4502K
Ludendorff, H., 1905, Publ. Astrophys. Obs. Potsdam, Vol. 15, Nº 50: 1905POPot..50....1L
Lupton, R.H. *et al.*, 1987, AJ, 93, 1114: 1987AJ.....93.1114L
Mészáros, Sz. *et al*., 2009, AJ, 137, 428: 2009AJ....137.4282M
Osborn, W. *et al.*, 2017, AcA, 67, 131: 2017AcA....67..131O
Paegert, M. *et al*., 2021: 2021arXiv210804778P
Scargle, J. D., 1982, ApJ, 263, 835: 1982ApJ...263..835S
Shappee, B. J. *et al*., 2014, ApJ, 788, 48: 2014ApJ...788...48S
Stassun, K.G. *et al*., 2019, AJ, 158, 138: 2019AJ....158..138S
Stetson, P. B. *et al*., 2019, MNRAS, 485, 3042: 2019MNRAS.485.3042S
Violat-Bordonau, F., 2022, OEJV, 222, 1: 2022OEJV..222....1V
Violat-Bordonau, F., 2024, OEJV, 244, 1: 2024OEJV..244....1V
Yu, J. *et al*., 2023, ApJS, 264, 41: 2023ApJS..264...41Y