PERIOD, AMPLITUDE AND LIGHT CURVE OF V38 IN M13

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Abstract. We have measured the period and amplitude of the new red variable star V38 (L414), of M13 (NGC 6205, C 1639+365), using CCDs and amateur telescopes (35.5-, 30.5- and 20.3-cm) from Spain in the years 2001-2005. The analysis of our CCD frames shows that V38 is a red variable star with a period of approximately 81 days, and low amplitude nearly 0.08 magnitudes: the period agrees with Osborn' s (1977) measures, but the period and amplitude with Kopacki' s et al. (2003) data. Also for 14 radial velocities published we find a pulsating period P = 83 days, consistent with the others three periods founded.

1. Introduction: the CCD Photometric Study Project

In the summer of 2000, we initiated a photometric study of the globular cluster M13 (NGC 6205) in order to locate and measure all its variable and suspected variable stars (as L414 or V38, Fig. 1), and to search variable stars of small amplitude; after elaborating a complete CCD chart (Fig. 2) to identify the variables, suspected variables and comparison stars (in May, 2001), based in Osborn' s paper (2000), we began to obtain digital images of the cluster using catadioptric telescopes of 20.3- and 30.5-cm (from 2001 to 2003), located in Spain (Caceres and Palma de Mallorca, respectively), and 20.3- to 35.5-cm in 2004 and 2005, located in Caceres, San Fernando (Cadiz) and Navas de Oro (Segovia), Spain, respectively. Both observatories are equipped with Starlight Xpress CCD cameras (MX516 was used in Caceres Observatory, MX916 at Palma de Mallorca and MX716 at Segovia), and SBIG ST7 (San Fernando, Cadiz). V filters were used in all telescopes, although no transformations were made to a standard system because the instrumental magnitude are very near (or equal) to V system. The CCD imagen were reduced using IRIS software (2001 and 2002) and AstroArt (2003 to 2005) with 5 to 8 non-variable stars taken from Osborn' s photometry, and periodogram analyses were performed using Bloomfield' s algorithm with Rafael Barbera' s software AVE (Analisis de Variabilidad Estelar).

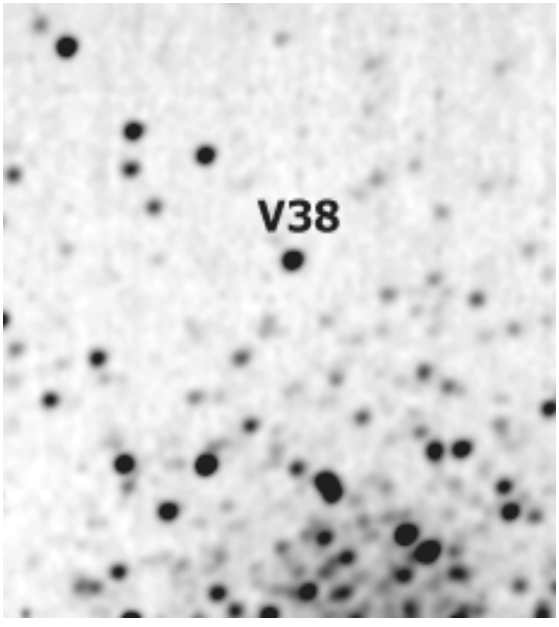

Fig. 1. CCD frame of M13 with V38 taken in V band from Mallorca (Spain). South is top, East to the right.

2. About L414, now V38

V38 (L414 in Ludendorff' s catalogue, 1905), or Arp III-56 (R.A.= 16h 41m 38.71s Dec.= +36º 25' 38.0", Equinox J2000), is a physical member of the cluster, according to proper motion (Cudworth and Monet, 1979), radial velocity and position in the H-R diagram; it lies at the tip of the AGB in a color-magnitude diagram. Popper (1947) classified L414 as of G8Ib spectral type: is a yellow super-giant star. Some photometric data (from Lyons et al., 1996) are: M_V: -1.94, T_{eff}: 4100º K, L/L_o: 3.08; other photometric data (Osborn, 2000): mag. V: 12.15, colour index B-V: 1.45.

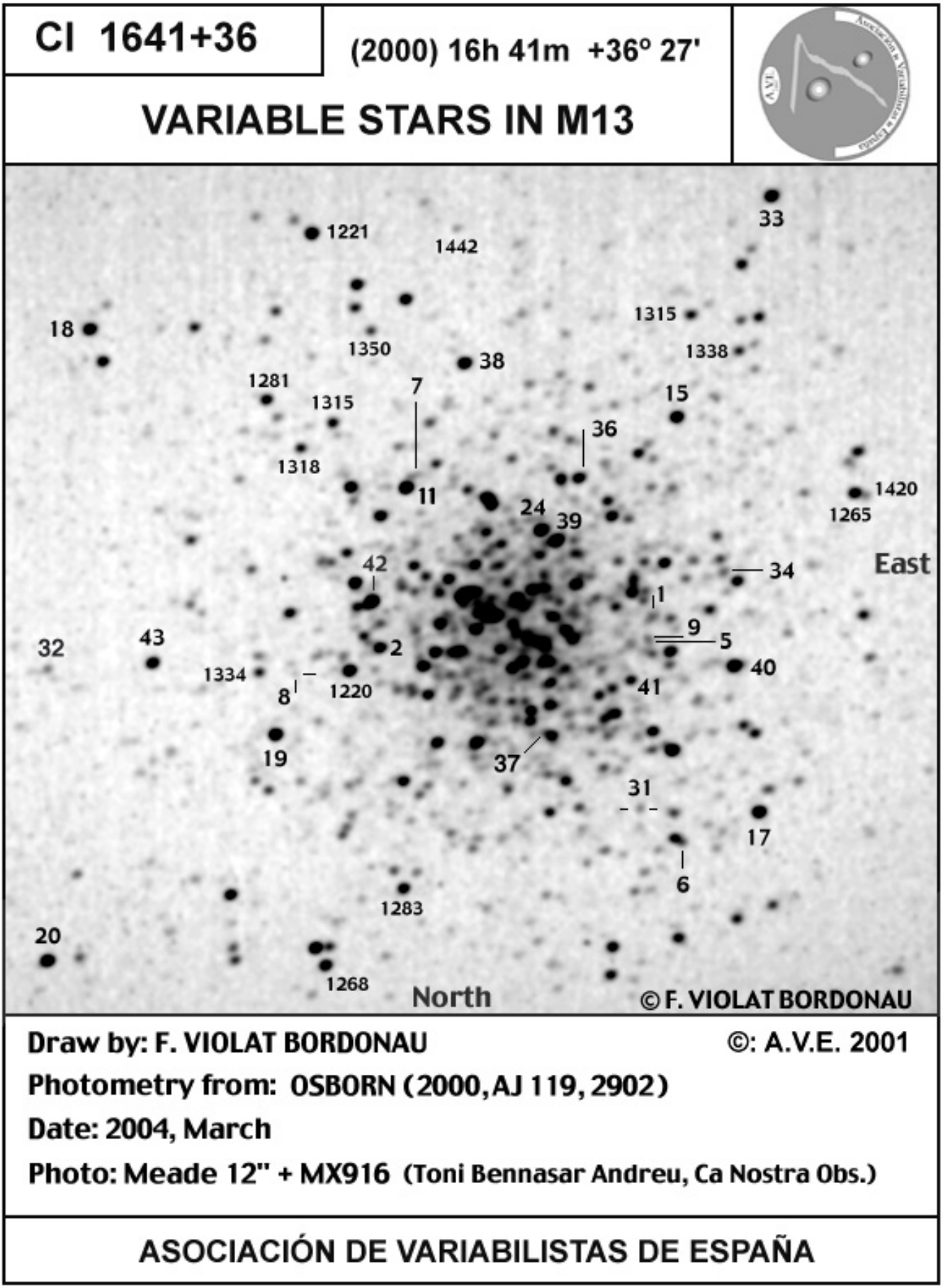

Fig. 2. CCD chart of M13, taken in V band, with variable (one or two digits) and comparison stars (four digits); South is top, East to the right. Drawn by Francisco Violat with V photometry taken from Osborn' s paper (2000); updated: 2004, March.

3. A suspected variable star: L414

L414 was announced as a new variable in Russev' s papers (1973). However Fuenmayor and Osborn (1974) could not detect any variability and concluded that L414 was non-variable, but Russev (1974) detected variations in L414 and indicated that this star is indeed variable. In 1977, Osborn and Fuenmayor found a variation in his observations of slightly larger than that of the reference stars, and proposed (indirectly, Table V) a period of 105 days with a B amplitude of 0.26 magnitudes. Welty (1985) could not see any variability in L414, because its small amplitude was below his B band detection limit of 0.2 magnitudes. From radial velocity measurements Lupton et al. (1987), asumed that L414 (and other 5 stars) was really a variable star. Shetrone (1994) found significant changes in the spectral variations in L414 (over 337 days) and in another 5 stars, wich might reflect long-term varibility, as Lyons et al. (1996) in his study about mass motions in the atmospheres of red giants in M13: L414 show very assymetric Hα emission line profile. Osborn (2000) finally concluded that L414 was probably a variable star. Only very recently Kopacki et al. (2003), working in 2001 (February-August) confirmed the variability of L414 (V38 in this paper) and gave an amplitude of only 0.07 mag. in V band, but not the period. (Average V-brightness: 12.118.)

4. Observations and data reduction

All our CCD observations in 2001 were taken without a V filter, but the spectral response of the unfiltered chip is near to that of the standard system (with 5 check stars). All observations from 2002 were taken with Johnson V-band filters; the exposure time was 15 s without filter, and 30-60 s with the filter. The calibration of the frames consisted of the *bias* and *dark* substraction as well as the *flat-field* correction; the average standard deviation of the CCD measurements of the 5 check stars are 0.005-0.014 magnitudes in the V band. The frame scale of the CCD images are 1.3”/pixel in the short focus (2000 mm) telescope.

The analysis of our 351 CCD images (2001-2002) using IRIS and AstroArt software for the photometric reduction, and the AVE periodogram and light curve analysis software, has show than L414 (V38 from 2003) is a red variable star. We identified a period of 115.5 days (the longest in M13) using the 351 CCD frames from 2001-2002 (data published in *Variable Star Section Circular*, no. 115, March 2003, British Astronomical Association), but are too long and wrong: the well-know effect of season produced spurious periods (period proposed indirectly by Osborn: 105 days).

New CCD measures were obtained in 2003, 2004 (with two telescopes: 35.5-cm at Segovia and 20.3-cm at Caceres) and 2005 (with three instruments: 20.3-cm at Caceres, 20.3-cm at Cadiz, and 30.5-cm at Segovia) using the same filter (V Johnson), and software (AstroArt) for the calibration and data reduction of the frames. In Fig. 3 we can see 501 measures (data taken by Violat' s frames) in the period 2003-2005. From our data we can see that V38 is really a red semiregular variable (SRd) of long period (81 days) and low-amplitude (0.16 magnitudes with random errors, but only 0.07-0.08 mag. really): this agrees with Welty' s results (low amplitude B< 0.2 magnitudes), also supports Osborn' s results (1977) of a low amplitude variable star (standard deviation of the measures: 0.058 mag.).

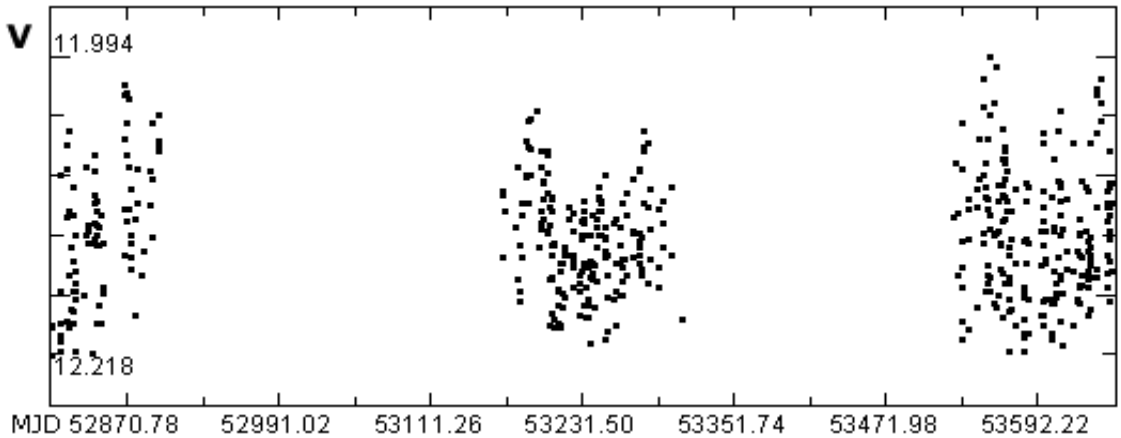

Fig. 3. Light curves taken by Violat (501 measures) in 2003, 2004 and 2005: the period is moderately long, and the *instrumental amplitude* (real amplitude +random errors) is equal to 0.224 mag (0.112 ± 0.056) in the range 11.994-12.218. Our instrumental mean magnitude are 12.106, but 12.15 in Osborn' s photometry and 12.118 in Kopaki' s work.

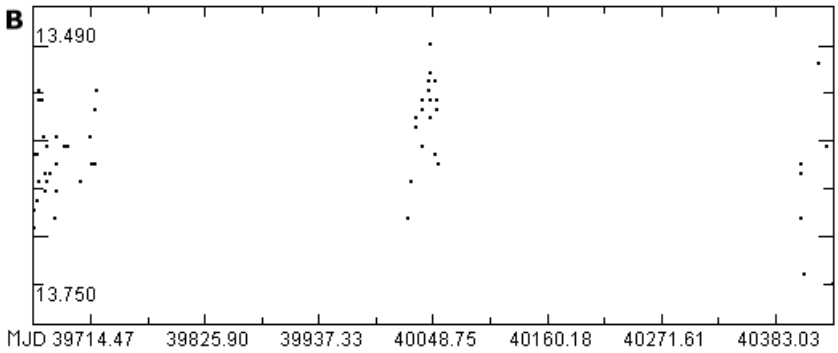

Fig. 4. Osborn's light curves taken in 1967-1969 in B band (55 points); L414 is a low amplitude variable star with this filter.

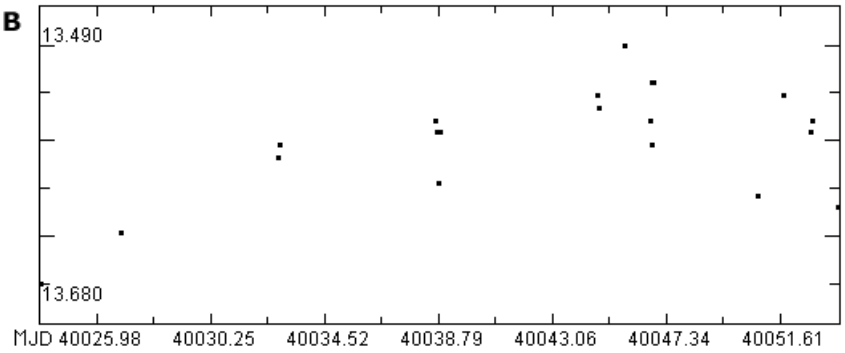

Fig. 5. Light curve, in B band, drawn from Osborn' s measurements in 1968: the period is moderately long (> 60 days) and the full amplitude near 0.19 magnitudes.

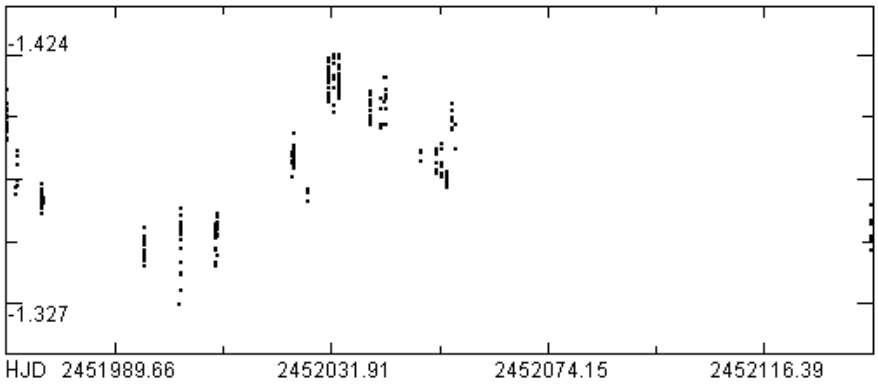

Fig. 6. Light curve, in V band, drawn from 272 Kopacki' s measurements (2001) in 23 night; visually the period is near 80 days. The amplitude, very small, is equal to 0.07 mag.

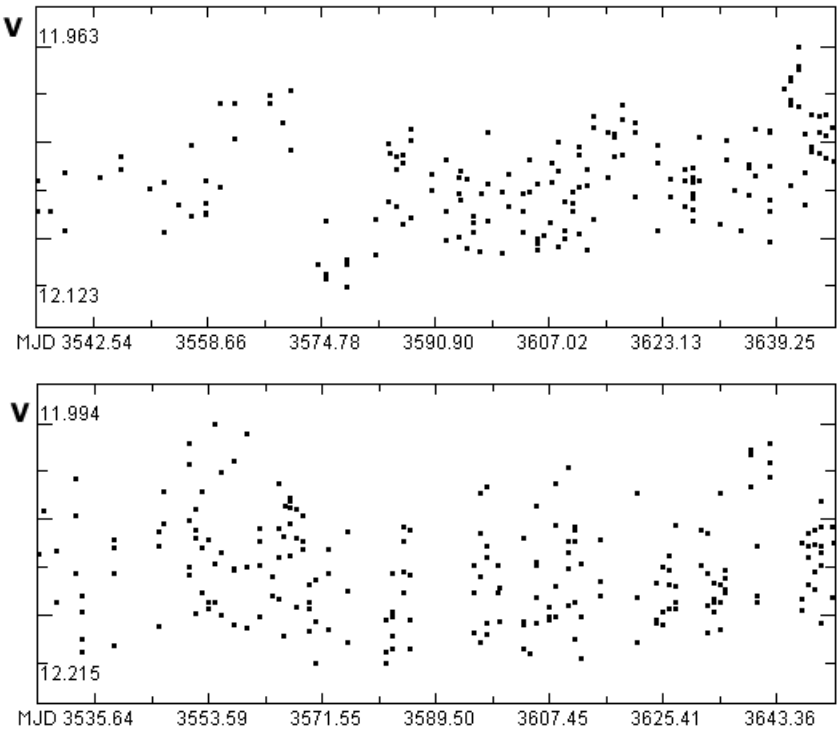

Fig. 7. Light curves taken by Arranz (up, 173 measures in 114 nights) and Violat (down, 217 measures in 127 nights) in V band in 2005; the amplitude are 0.160 and 0.221 mag. respectively. The mean magnitude from Violat' s measures are 12.11 (12.15 from Osborn's photometry).

5. Period and amplitude

Osborn and Fuenmayor published (1977) 55 measures in B band taken in 1967-1969 (Fig. 4 and 5), and Kopacki et al. (2003) 272 measures in V band taken in 2001 (on 23 nights between 2001 February 27 and August 1, Fig. 6); our CCD frames in 2001 were carried over a period of 129 days (JD 52076-52204) and covered the last weeks of Kopacki' s observations (June to August).

We have examined these measures of both teams the analysis of Osborn' s measures with AVE software (the most probable period are in the range 10-200 days) give a period of 80.2 days (and not 105 days published in this paper), with maximum in HJD 2440045.7827, Fig. 8. The analysis of Kopacki' s measurements with AVE give a period of 80.8 days (Fig. 9), with a maximum in HJD 2452032.4918. Both periods produced smoother light-curves.

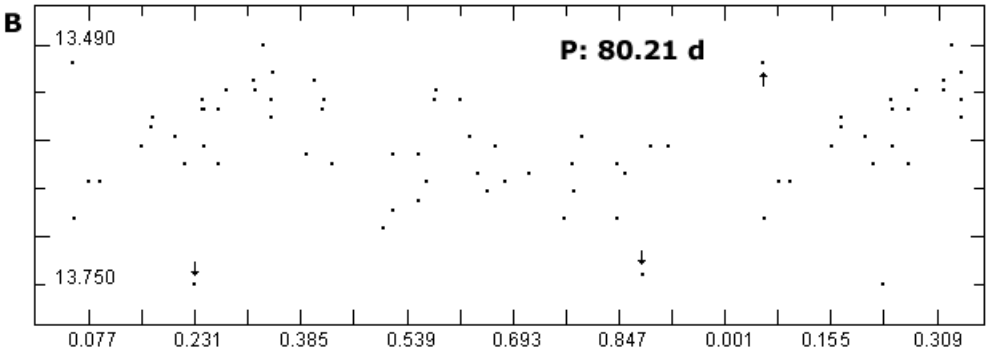

Fig. 8. Light curve, in B band, taken from 55 Osborn' s measurements and with a period of 80.21 days: only 3 points (marked with arrows) disagrees with this period.

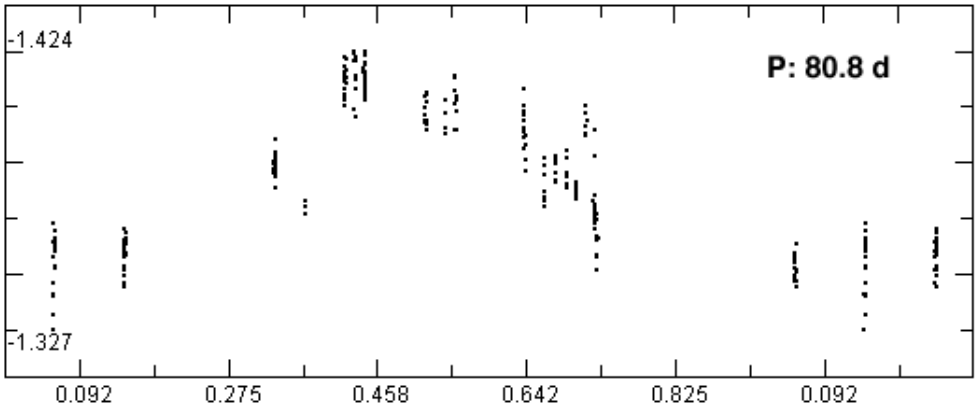

Fig. 9. Light curve of V38 plotted using 272 measures of Kopacki and a period of 80.8 days: only one night (phase 0.73) disagree with this period.

Using our new CCD measurements (240 in 2004 and 410 in 2005, Fig. 7) AVE give a period of 81 days: this agrees with Osborn' s and Kopacki' s data, and produced a well light curve (Fig. 10); only four "bad photometric night" (six points in phase 0.732, and nine near 0.899) disagrees with this.

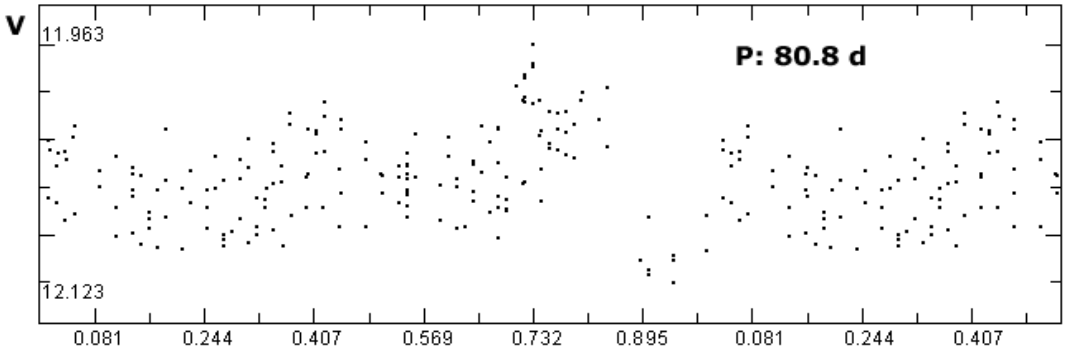

Fig. 10. Light curve V 38 plotted using 173 measures of Arranz and a period of 80.8 days: only four *bad photometric nights* (15 points) disagrees whit this; full amplitude: 0.160 mag. with random errors.

The amplitude measured by Arranz (35.5-cm) is equal to 0.16 (0.070 ± 0.045) magnitude in V band; the amplitude measured by Violat or Diez (booth with 20.3-cm) are 0.221 and 0.222 mag. respectively (0.091 ± 0.065 mag. and 0.100 ± 0.061 mag.). These data agree with Kopacki' s results; V38 is a low

amplitude (0.07-0.09 mag.) and long period (near 81 days) semiregular variable star.

Some maxima measured by us are: HJD 2453196.16, 2453281.37 and 2453564.30; mean period using this data: from 81 to 86 days (because is a semiregular variable star).

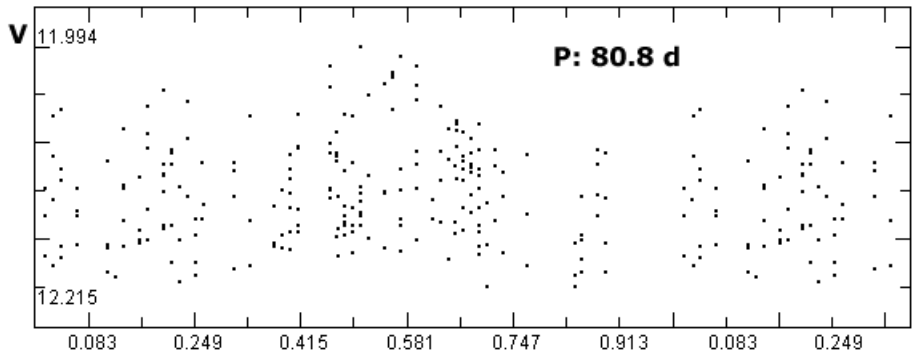

Fig. 11. Light curve taken in 2005 using 217 measures of Violat with a period of 80.8 days; full amplitude: 0.221 magnitudes, mean magnitude: 12.105.

Fig. 11 shows the light curve taken in 2005 with Violat' s measures in the range 11.994-12.215 and phased with 80.8 day, altough using all the Violat' s CCD filtered measures (2003-2005), working with a small telescope (20.3-cm), the ligh curve are very consistent with a period of 85.76 days (Fig. 12). This number is almost 1/4 of the period (over 337 days) measured by Shetrone (1994) in the changes in the spectral variations in L414.

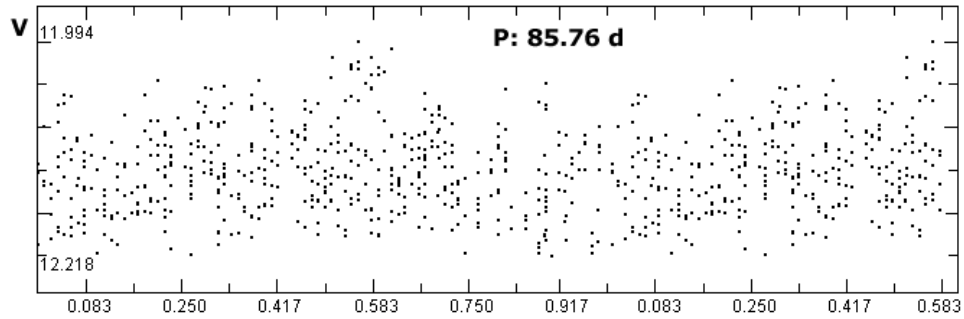

Fig. 12. Light curve plotted using 501 measures of Violat with a period of 85.76 days; amplitude: 0.224 magnitudes, mean magnitude: 12.106.

Variable stars can be identified by their light curves (as in this paper), or by their high standard deviation in the measurements (photometric or radial velocities) compared with other non-variable stars of comparable magnitude. Table I shows 14 radial velocities (Fig. 13) from some studies of globular-clusters giants collected by us (a: Lupton et al., 1987; b: Shetrone, 1994; c: Lyons et al., 1996; d: Soderberg et al., 1999, and e: Pilachowski et al., 2000), but none from Webbink' s papers (1981).

TABLE I

MEASURED RADIAL VELOCITIES FOR V38

HJD	RV (km s^{-1})	Reference
2,441,073.	-240.50 ± 1.10	a
2,441,103.	-240.57 ± 0.80	a
2,441,461.	-241.38 ± 0.97	a
2,442,196.	-242.27 ± 0.76	a
2,444,030.	-242.07 ± 0.46	a
2,444,032.	-243.71 ± 0.45	a
2,444,416.	-239.64 ± 0.49	a
2,444,417.	-237.87 ± 0.45	a
2,448,458.724	-240.9 ± 0.4	b
2,448,795.954	-239.8 ± 0.7	b
2,448,795.954	-241.8 ± 0.1	b
2,449,028.	-223.0 ± 1.4	c
2,449,138.	-238.99 ± 0.44	d
2,451,322.783	-239.81 ± 0.39	e

We have removed only one velocity (c, -223.0 ± 1.4 km s^{-1}) because is still unexpectedly low (average velocity for M13: -245.5 ± 1.0 km s^{-1}, Soderberg et al., 1999) and were made between 1993 February 7-12 (date unidentified or uncertain).

For this 13 radial velocities we find a pulsating period P equal to 83 days (Fig. 14, velocity curve): this new period is consistent with the others photometric ones and agrees with them. Perhaps, further new data are needed to confirm velocity variations with P = 83 days.

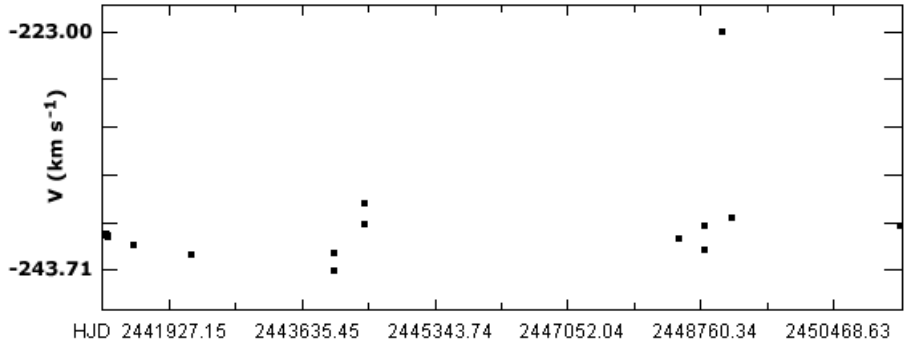

Fig. 13. All the 14 measures taken for references; only one measure (-223 km s^{-1}) disagree of the rest.

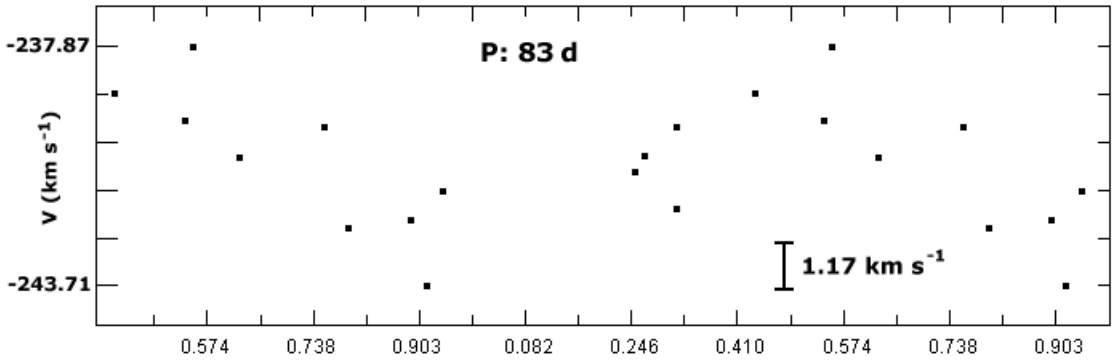

Fig. 14. Velocity curve for V38 drawn using 13 measures assembled by us, and taken of some studies of globular-clusters giants. Period = 83 days, velocity changes = 5.84 km s^{-1}. Two cycles are plotted.

6. Summary

Using photographic and CCD measurements taken in 1967-1969 (Osborn) and 2001 (Kopacki et al.) respectively, published in profesional papers, we identified a period of 80.2 and 80.8 days respectively for the red star L414, *V38* from 2003. From our first unfiltered CCD measures (2001) AVE gave a period of 115 days and an amplitude nearly 0.14 magnitudes; this period are too long and wrong, but very near to Osborn' s indirectly published period (1977). Using our new CCD filtered measurements (2002 to 2005), working with two 20.3-cm, one 30.5- and one 35.5-cm telescopes from Spain, AVE give a period of 81 days (more short and accurate) and a low amplitude: 0.070 ± 0.045 mag. in V band (Arranz) and 0.091 ± 0.065 mag. and 0.100 ± 0.061 mag. (Violat and Diez, respectively). This agrees with Osborn' s and Kopacki' s photometric data, and produce a well smooth light curves with all measurements: only 2003, 2004, or 2005 separately, as the whole 2003 + 2004 + 2005. Also, for 13 radial velocities taken from some studies, we find a pulsating period P = 83 days in well agreement with the others three periods. V38 is a semiregular variable star (SRd) of low amplitude and moderately long period.

Acknowledgements

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