OBSERVATIONS OF THE RRC VARIABLE LINEAR 1169665 WITH THE ROBOTIC TELESCOPE TAROT

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Abstract

LINEAR 1169665 is a RR Lyrae of sub-type c discovered by the asteroid survey LINEAR. The robotic telescope TAROT at Calern Observatory has observed it between the years 2006 and 2015. The present study of TAROT data as well as those from the surveys ASAS-SN (2012-2019) and LINEAR (2002-2008) shows that this star presents a period modulation with a period of 1800.1 days (4.9 years) but with no significant variation of magnitude at maximum.
This phenomenon is similar to the one found in KEPLER data for the RRc KIC 2831097 (Sódor et al., 2017) which was suspected to be the result of a light time effect in a double stellar system. The large modulation period and the lack of amplitude modulation exclude it to be attributed to a Blazhko effect. But alternatively to the light time effect this phenomenon might be due to a new modulation phenomenon with long period affecting at least RRc stars.

1 Introduction

LINEAR 1169665 is a c sub-type RR Lyrae observed by TAROT (Klotz et al., 2008, 2009) at Calern Observatory in the field of AE Leo which is routinely surveyed in the frame of GEOS RR Lyr Survey (GRRS) (Le Borgne et al., 2007, 2012). The star was discovered by the survey Lincoln Near-Earth Asteroid Research (LINEAR), a program searching for asteroids since 1998. Sesar et al. (2011) have used LINEAR image database to search for time variable objects. In particular, they published a general catalog of periodical variables (Palaversa et al., 2013) and a more complete catalog restricted to RR lyr stars (Sesar et al., 2013) to which LINEAR 1169665 belongs. Sesar et al. (2013) give a period of 0.412982 days and an amplitude of 0.299 magnitude, magnitude at maximum being 14.432.

2 Tarot observations and data mining

TAROT CCD images of LINEAR 1169665 were obtained between JD 2453739 (2006 January 3) and 2457047 (2015 January 24). Photometry reduction of the images used SExtractor software (Bertin and Arnouts, 1996) to derive CV magnitudes of all stars in the field. The images are obtained with no filter and are calibrated with V magnitudes of comparison stars. Magnitudes of LINEAR 1169665 and comparison star UCAC4 538-052434 (table 1) were then extracted from SExtractor files. After selection on internal signal to noise ratio of the TAROT images it remains 1106 measurements covering a time interval of 9 years.

star name	ra(J2000)	dec(J2000)	B	V	B-V
LINEAR 1169665	11:26:44.1168	+17:51:11.556	14.474	14.426	0.048
UCAC4 538-052434	11:26:55.731	+17:33:59.46	12.103	11.486	0.617

Table 1 – Coordinates of LINEAR 1169665 and comparison star used for reducing TAROT data. Magnitudes are those given by UCAC4 catalog (Zacharias et al., 2012).

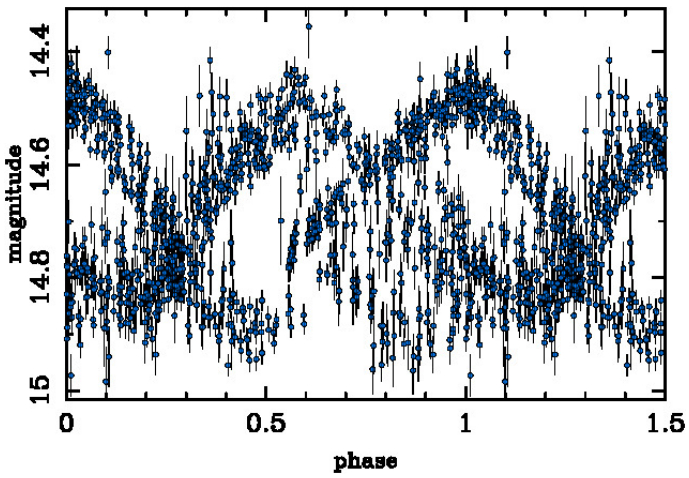

Figure 1 – Folded light curve of TAROT data using a period of 0.4129588 days.

In order to check Sesar et al. (2013) period, we performed a frequency analysis on TAROT data using Schwarzenberg-Czerny (1996) algorithm. We found a period of 0.4129588 days similar to Sesar et al. (2013) result. Figure 1 shows the light curve of TAROT measurements folded with the period found and an epoch of HJD 2456001.593. One sees that the light curve appears to be bimodal which could be interpreted as the result of a sudden period change during the observation time interval. The measurements of individual maxima from TAROT data allow to explore this hypothesis. Nine maxima were computed and are listed in table 2 using the elements HJD 2456001.593 + 0.4129588 E.

The O-Cs of the maxima indeed show a sudden drop of about 4 hours (compared to the period of 10 hours) between JD 2456367 (2013 March 15) and JD 2456696 (2014 February 7).

More information is available from survey public data. We collected CCD measurements from ASAS-SN (Shappee et al., 2014; Kochanek et al., 2017) from web site https://asas-sn.osu.edu/ and from the discovery survey LINEAR. Concerning LINEAR a gzip-ed tar archive containing star light curves may be downloaded from
http://faculty.washington.edu/ivezic/linear/PaperIII/PLV.html. LINEAR data cover a time interval from JD 2452614 (2002 December 5) to JD 2454619 (2008 June 1^{st}) and ASAS-SN

Maximum HJD	**O-C (jous)**	E	Number of measurements	Duration of observation (hours)
2456001.593 ±0.010	**0.000**	0	52	4.8
2456006.5590±0.0097	**0.010**	12	44	3.6
2456288.636 ±0.011	**0.037**	695	36	3.8
2456310.534 ±0.010	**0.048**	748	46	4.9
2456327.4695±0.0097	**0.052**	789	36	4.0
2456367.507 ±0.012	**0.033**	886	50	4.8
2456696.507 ±0.014	**-0.096**	1683	41	5.3
2456725.434 ±0.014	**-0.076**	1753	50	4.6
2456782.437 ±0.013	**-0.061**	1891	42	4.1

Table 2 – Observed individual maxima of LINEAR 1169665 from TAROT data.

data from JD 2455969 (2012 February 11) to JD 2458486 (2019 January 2). The three data sets are then complementary to cover a time interval of 17 years from December 2002 to January 2019.

Individual maxima are hardly obtained from LINEAR and ASAS-SN data because both collect few measurements each night. On the other hand, the light curves of RRc stars show a flat maximum, and even sometimes a double maximum: it is then better to define mean maxima determined on folded light curves from given time intervals. Given the quite small number of measurements (table 3) of each surveys, we built folded light curves on intervals of one year (see light curves in appendix). Table 3 lists the mean maxima obtained in such a way. Note that 2006 LINEAR data before November are not compatible with 2005 and 2007 data due to period change. After November 2006, data are compatible with 2007 data. However, there are no measurements at maximum in 2006. In 2012 and 2013, there are not enough measurements in ASAS-SN data to estimate a mean maximum.

Put together, the 19 maxima from the three surveys suggested a period slightly longer than the one determined by the spectral analysis of TAROT data. We determined elements which satisfy all the maxima as a mean, with however an O-C amplitude of ±1h48m:

$$2456001.568 \; + \; 0.412963 \; E \qquad (1)$$

3 Period modulation

The O-C curve using elements (1) is displayed in figure 2. The dispersion is large but we are tempted to see a periodicity in the O-C variation. We then performed a frequency analysis (Schwarzenberg-Czerny (1996) algorithm) and found a period of 1800.1 days as shown in figure 3 which confirm the visual impression.

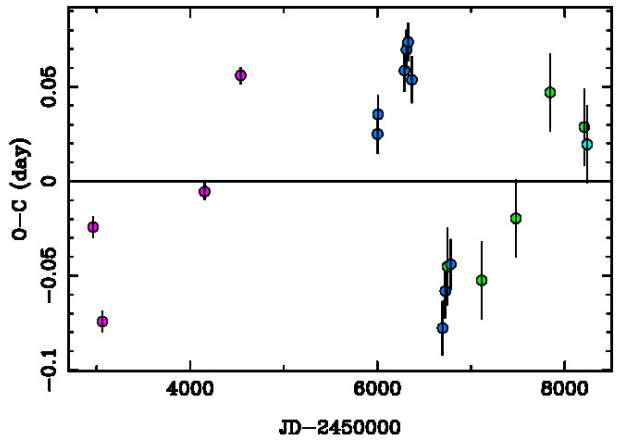

Figure 2 – O-C curve of LINEAR 1169665 maxima. TAROT data correspond to blue points. Purple points are LINEAR data. ASAS-SN data are represented by green points for V filter and turquoise for g filter.

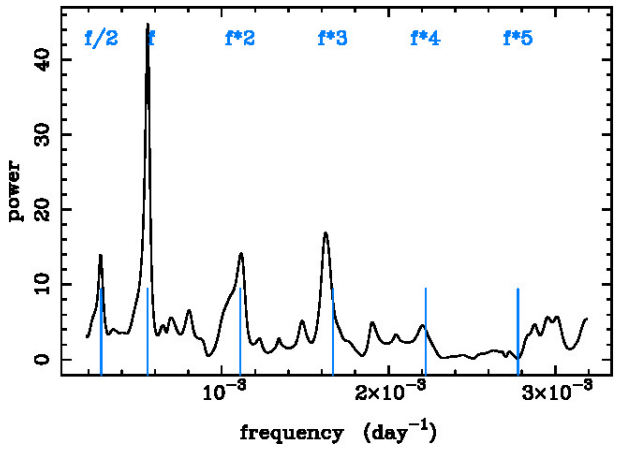

Figure 3 – Periodogram plot for O-C periodicity. The value of main frequency f is 5.5552 10^{-4} d^{-1} corresponding to a period of 1800.1 days.

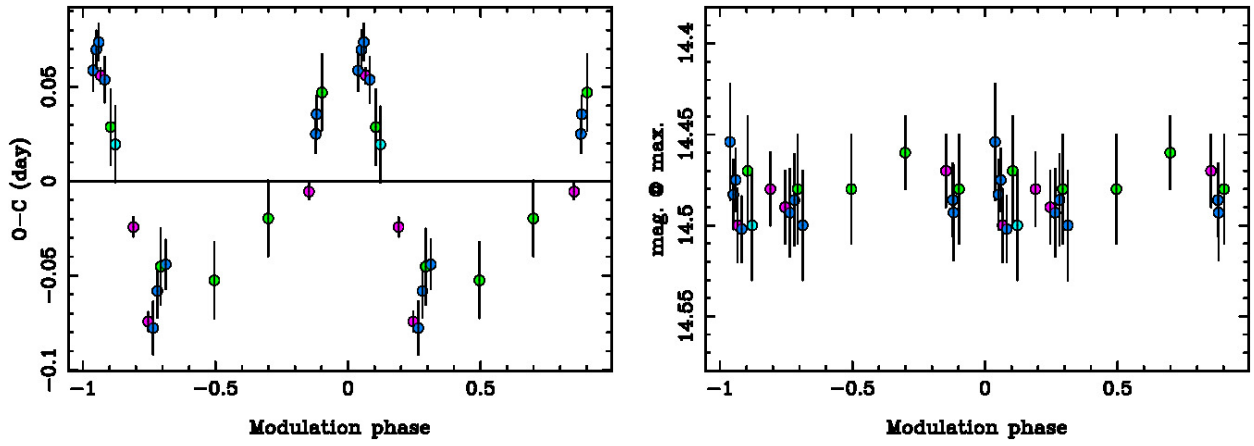

Figure 4 – O-C curve and magnitude at maximum folded on modulation period of 1800.1 days. Color codes are the same as for figure 2

year	Number of measurements	Mean maximum HJD
	LINEAR	
2002-2003	108	2452962.962±0.005
2004-2005	75	2453062.849±0.005
2006	50	
2007	20	2454154.792±0.004
2008	52	2454539.735±0.004
	ASAS-SN	
2012-2013	68	
2014	86	2456747.334±0.02
2015	134	2457112.386±0.02
2016	180	2457478.304±0.02
2017	254	2457843.438±0.02
2018	130	2458208.471±0.02

Table 3 – Observed mean maxima of LINEAR 1169665 from LINEAR and ASAS-SN surveys.

Table 4 displays a summary of the maxima measured from the data of TAROT, LINEAR and ASAS-SN surveys. The O-C are calculated with the elements (1) and are those plotted in figure 2. The magnitudes at maximum are listed in the third column. Tarot and LINEAR give magnitudes in CV photometric filter. ASAS-SN images are filtered and magnitudes are given for V filter with the exception of the last maximum which was measured on g filter data. The magnitudes of LINEAR and ASAS-SN surveys are quite similar, even if the last maximum was obtained with g filter, bluer than V filter. Tarot magnitudes, however, seem shifted relative to the other surveys. This appears clearly in the mean maximum magnitude:
- TAROT: 9 max., mean maximum mag. 14.486, standard deviation 0.0146 mag.
- LINEAR and ASAS-SN: 10 max., mean maximum mag. 14.401, standard dev. 0.0129 mag.
Unlike O-C, magnitude at maximum is constant over the 17 years of observation, within measurement precision. The difference of 0.081 magnitudes between TAROT and the other series may be due to the calibration method: a single comparison star for TAROT and ensemble calibration for the other series. O-C curve and magnitude at maximum folded on modulation period of 1800.1 days are plotted in figure 4. The origin time used is 2456220. This value was chosen as an estimation of the maximum of O-Cs. The amplitude of the O-C modulation is 0.15 days. We subtracted 0.081 magnitudes from magnitude at maximum of the TAROT data in order to equal the mean values of the 3 series.

Figure 5 shows a sample of folded light curves of TAROT data for two seasons, 2012-2013 and 2013-2014. The other seasons do not have complete light curves. The phases are computed with elements (1). Note the phases of the maxima corresponding to the O-C seen in figure 2 and 4. These two seasons are before and after the 2013 sudden drop of O-Cs.

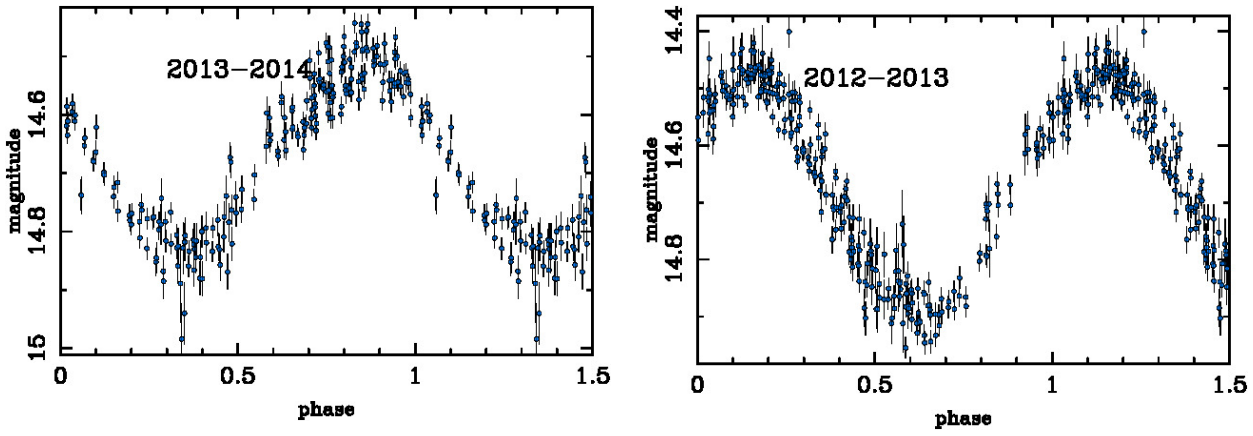

Figure 5 – Folded light curve of TAROT data for two seasons, 2012-2013 and 2013-2014. The phases are computed with elements (1)

4 Interpretation and conclusion

Analyzing measurements of the RRc LINEAR 1169665 made by telescope TAROT in Calern from 2006 to 2015 and by the surveys LINEAR (2002-2008) and ASAS-SN (2012-2019), we have found that this star exhibits a period modulation with a period of 1800.1 days. No modulation is found in the magnitude at maximum. Because the period of the modulation is very long and the magnitude at maximum shows no modulation, we can say it is hardly a Blazhko effect. The behavior of LINEAR 1169665 looks like the one of the RRc star KIC 2831097 in many aspects. (Sódor et al., 2017) have shown that KIC 2831097 observed by KEPLER satellite have period modulation with a period of 753 days with no amplitude modulation. The amplitude of the variation of O-C is 0.036 days.
Logically, this behavior can be interpreted as a light time effect (LiTE) in a double stellar system. In the case of KIC 2831097, (Sódor et al., 2017) translated the O-C amplitude as the time necessary to the light to travel across the orbit. They found as projected semi-major axis $a\ sin\ i = 3.143AU$, where i is the obliquity of KIC 2831097 orbit on the line of sight. They also computed that the companion should have a mass of 8.4 $M_\odot$ assuming the RR Lyr has a mass of 0.6 $M_\odot$. For LINEAR 1169665, the binarity hypothesis interprets the modulation period of 1800.1 days as the orbital period and the amplitude of the O-C of 0.15 days as the light travel time across the orbit corresponding to a projected orbit size of 13 AU. Given the shape of the O-C folded curve, similar to KIC 2831097, the ellipticity of the orbit should be large. In such case, the light travel time we calculate does not correspond the projection of the major axis but to another cord, necessarily smaller.

Another interpretation is that we are facing to a new modulation type affecting RRc (at least) differing from Blazhko effect with a very long period and no amplitude modulation.

Maximum	O-C (days)	Magnitude at maximum	Survey
2452962.962±0.005	-0.0242	14.40±0.02	LINEAR
2453062.849±0.005	-0.0743	14.41±0.02	LINEAR
2454154.792±0.004	-0.0055	14.39±0.02	LINEAR
2454539.735±0.004	0.0560	14.42±0.02	LINEAR
2456001.593±0.01	0.0250	14.486±0.02	Tarot
2456006.559±0.0097	0.0354	14.493±0.026	Tarot
2456288.636±0.011	0.0587	14.454±0.032	Tarot
2456310.534±0.01	0.0697	14.483±0.019	Tarot
2456327.4695±0.0097	0.0737	14.475±0.017	Tarot
2456367.507±0.012	0.0538	14.502±0.018	Tarot
2456696.507±0.014	-0.0777	14.493±0.024	Tarot
2456725.434±0.014	-0.0581	14.486±0.025	Tarot
2456747.334±0.02	-0.0452	14.40±0.03	ASAS-SN
2456782.437±0.013	-0.0440	14.500±0.03	Tarot
2457112.386±0.02	-0.0525	14.40±0.03	ASAS-SN
2457478.304±0.02	-0.0197	14.38±0.02	ASAS-SN
2457843.43 ±0.02	0.0470	14.40±0.03	ASAS-SN
2458208.471±0.02	0.0287	14.39±0.03	ASAS-SN
2458239.434±0.02	0.0195	14.42±0.03	ASAS-SN; g filter

Table 4 – Summary of observed maxima of LINEAR 1169665.

5 Acknowledgements

This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France (Wenger et al., 2000) and of the VizieR catalogue access tool, CDS, Strasbourg, France. The original description of the VizieR service was published in A&AS 143, 23, http://vizier.u-strasbg.fr/viz-bin/VizieR
This research also has made use of the International Variable Star Index (VSX) database, operated at AAVSO, Cambridge, Massachusetts, USA. https://www.aavso.org/vsx/index.php and of the GEOS database of RR Lyr stars (Le Borgne et al., 2007) hosted at Institut de Recherche en Astrophysique et Planétologie, Toulouse, France http://rr-lyr.irap.omp.eu/dbrr/
The authors thank the referee for his useful comments.

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A Appendix: Mean light curves

The figures 6 and 7 show the yearly folded light curves of LINEAR 1169665 from LINEAR and ASAS-SN surveys used to compute mean maxima. For each curve, the phase origin corresponds to the mean maximum as given in table 3, with the exception of 2006 LINEAR curve.
The comparison of figures 5 to 7 gives the impression that the hump before maximum is more pronounced on some folded light curves, for example, LINEAR 2002-2003 and 2008. If real, it is difficult to say with the present data if this is connected to the period modulation or to the difference of detector spectral response.

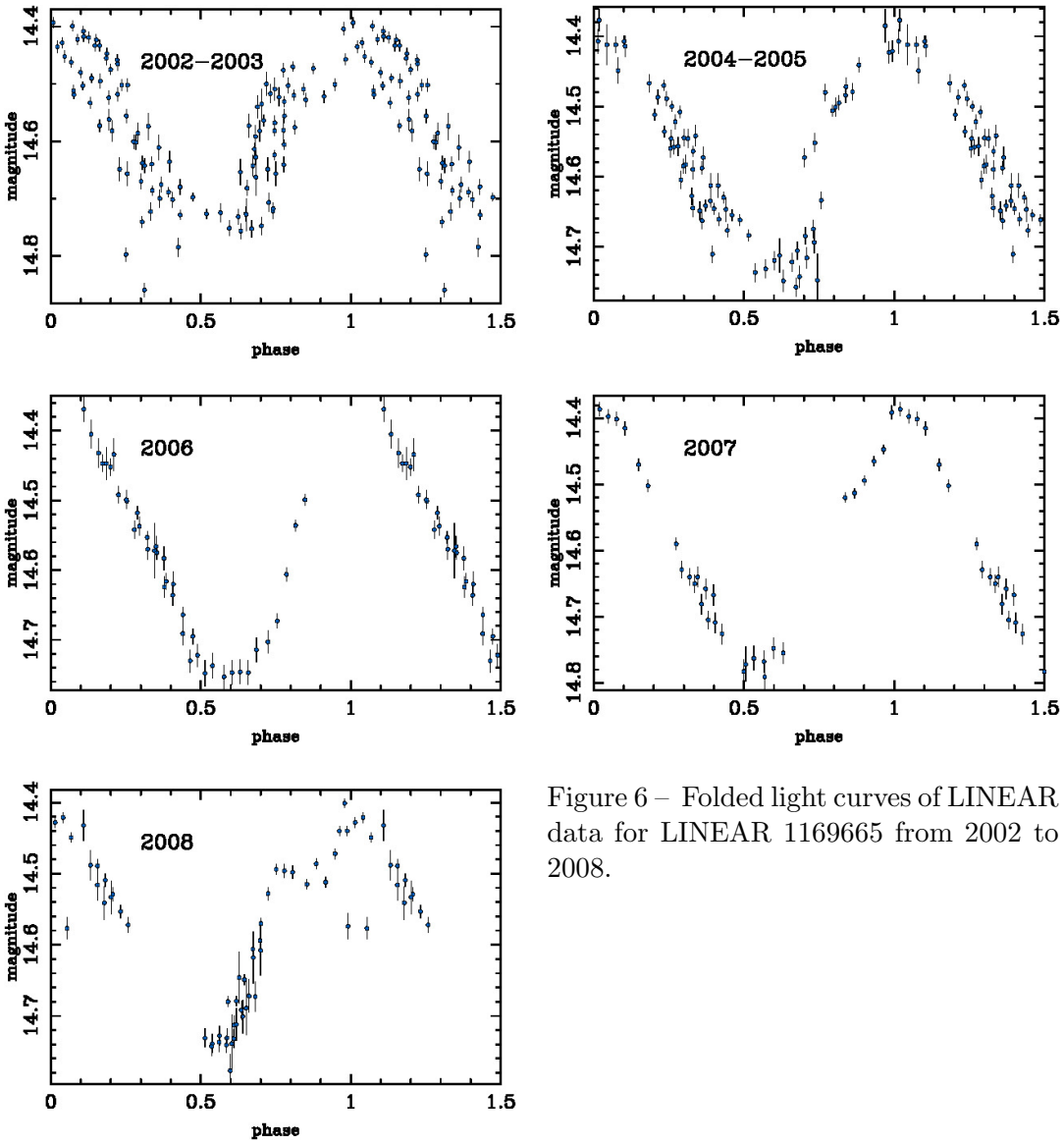

Figure 6 – Folded light curves of LINEAR data for LINEAR 1169665 from 2002 to 2008.

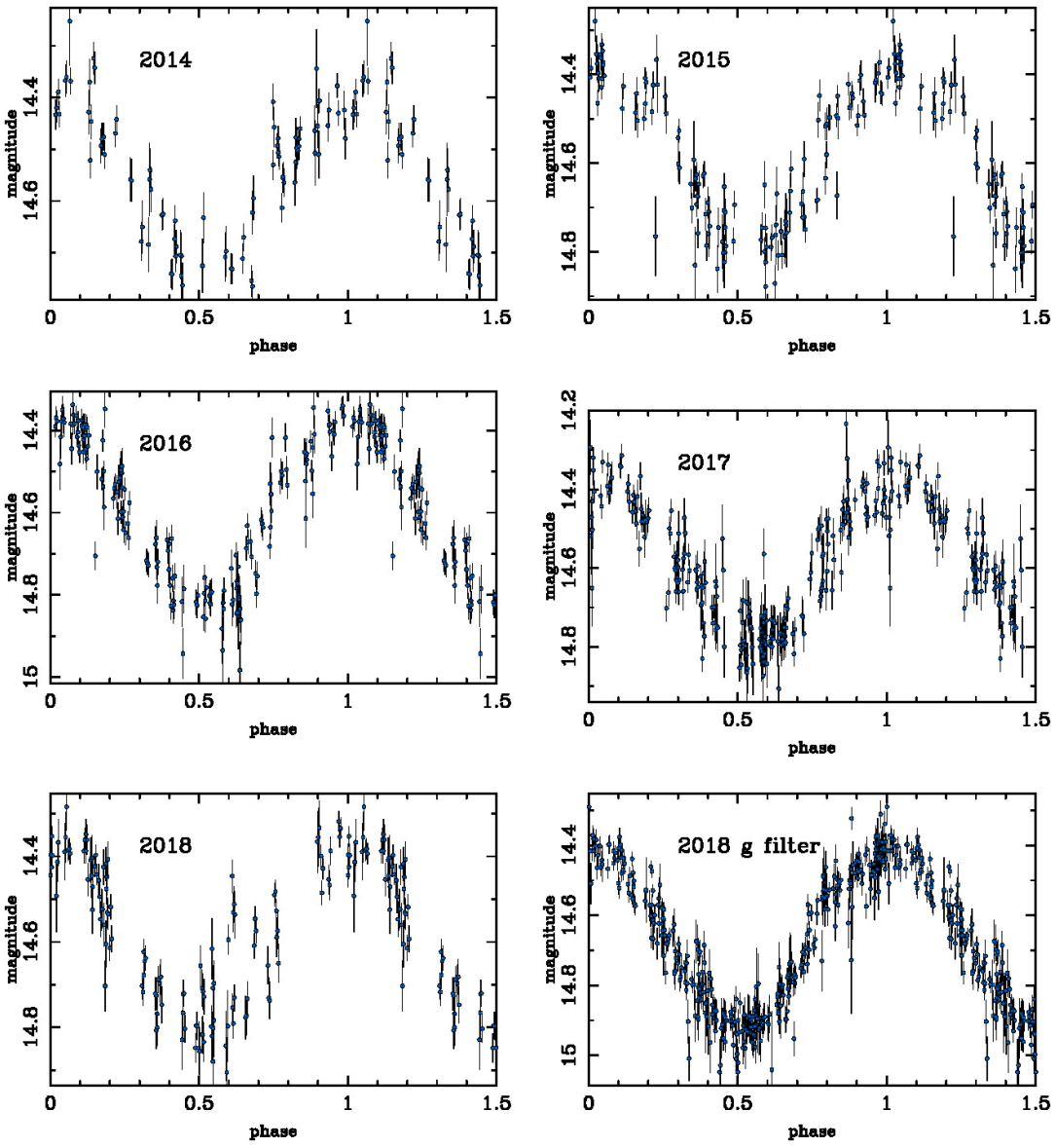

Figure 7 – Folded light curves of ASAS-SN data for LINEAR 1169665 from 2012 to 2018. Filter used is V, except for the last curve which is obtained with g filter.