New Variable Stars Discovered by Data Mining Images Taken during Recent Asteroid Photometric Observations. Results from the Year 2015

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Abstract During the past year the authors observed several asteroids for the purpose of determining the rotational period. Typically, this task requires a time series images acquisition on a single field for all the night, weather permitting, for a few nights although not consecutive. Routinely checking this "goldmine," allowed us to discover 14 variable stars not yet listed in catalogs or databases. While the most of the new variables are eclipsing binaries (GSC 01394-01889, GSC 00853-00371, CSS_J171124.7-004042, GSC05065-00218, UCAC4-386-142199, UCAC4 398-127457, UCAC4 384-148138, UCAC4 398-127590, UCAC4-383-155837, GSC-05752-01113, GSC 05765-01271), a few belong to RR Lyrae class (UCAC4 388-136835, 2MASS J20060657-1230376, UCAC4 386-142583). Since asteroid work is definitely time-consuming, follow-up is quite a difficult task for a small group. Further observations of these new variables are therefore strongly encouraged in order to better characterize these stars, especially RR Lyrae ones whose data combined with those taken during professional surveys seem to suggest the presence of a Blazhko effect.

1. Introduction

Taking CCD images of asteroids for the purpose of plotting their light curves in order to work out their synodic rotational period is always rewarding and very often funny. Although each author has his own targets or program to carry on, very often we collaborate in order to cover gaps due to personal commitments or bad weather, using the advantage of multiple sites. Even if the asteroid is a fast rotator (3–5 hours), it must be followed as long as possible and hopefully all night long on a few consecutive nights to cover all the phased curve. Therefore, each night, one telescope is aimed at the same field for enough hours to work out a light curve variation, if any, for each object in the same field. At the end of each session, all the images are stored on a cloud storage system and shared between the authors who in turn perform the photometric analysis of the asteroid data. Applying this collaboration protocol during the past year, also thanks to the remote control capabilities of the Astronomical Observatory of the University of Siena inside the facilities of the DSFTA (Department of Physical Sciences, Earth and Environment), our group has observed for about 190 nights collecting over 20,000 valid photometric measurements. As a side effect, the group discovered also 14 new variables, specifically, 11 eclipsing binaries and 3 short period pulsators. Indeed, after photometric analysis of the asteroid has been done, data are analyzed again with suitable software packages like C-MUNIPACK (Motl 2011) and MPO CANOPUS (Warner 2012) which highlight all the objects in the images of the series which are not constant over the whole session. Once a new variable has been found, photometric analysis of the object is performed with the software packages MAXIMDL (Diffraction Limited 2012) or MPO CANOPUS (Minor Planet Observer 2010). After adequate zero-point calibration, data have been added to those available from satellite or automated surveys as ASAS-3 (All Sky Automated Survey; Pojmański 2002), CRTS (Catalina Real-Time Transient Survey; Drake 2014) and NSVS (Northern Sky Variability Survey; Wozniak 2004). With these data merged together, a final period analysis is performed with PERANSO software (Vanmunster 2007). In the end, new variable stars were added to the AAVSO Variable Star Index (VSX; Watson, *et al.* 2014), to share them with the larger community of professional and amateur astronomers. Follow up of these stars is encouraged since it is a hard task for a small group of individuals.

2. Instrumentation and methods

The observations were carried out from December 2014 to October 2015. All the observatories involved in this study are located in Italy; one of these is located inside the facilities of the University of Siena, while the others are privately operated. The main features of the equipment used are listed in Table 1.

All the computers' clocks were automatically synchronized via NTP servers. Even considering net delay, the precision on times is less than one second. All the recorded times were UT. Typically, images were taken unfiltered to increase signal intensity. However, at the astronomical observatory of the

Table 1. Observers and main features of the instruments used.

Observer	Telescope	Filter	CCD
Franco (A81)	8" SCT f/5.5	C	SBIG ST7-XME
Marchini (K54)	12" MCT f/5.6	C	SBIG STL-6303e (bin 2 × 2)
Papini (K49)	10" SCT f/10	C	SBIG ST9-XME
Salvaggio	9.25" SCT f/10	C	SBIG ST8-XME (bin 2 × 2)

University of Siena, a parafocal Clear filter which transmits all wavelengths from UV to far IR was used. Exposure times were always between 5 and 8 minutes, depending on the asteroid apparent magnitude. All the images were calibrated with dark and flat-field frames by the same observer who acquired them.

Variable star search in the calibrated images has been performed with the software packages C-MUNIPACK and MPO CANOPUS. They are based on the relation between the standard deviations of the brightness of the stars and their mean brightness. The program reads all photometry files and computes the mean brightness and standard deviations of brightness of all stars. The algorithm automatically removes stars that are missing on the majority of source frames. For stars of lesser magnitude the deviation of brightness exhibits a higher value than the deviation for stars of greater brightness.

Once a new variable has been found, photometric analysis is performed with the software packages MAXIMDL or MPO CANOPUS. Although being equivalent from the point of view of photometry quality, MPO CANOPUS has a few tools for checking comparison stars used for photometry. Bright enough stars in the field of view were chosen for the comparison and check stars. Unfortunately, not so many bright stars were present, so that often color index did not match the color index of the variable as much as desired. Aperture photometry was done on each subset of data using the optimum aperture radius (Howell 1991) in order to maximize the SNR. Magnitude are given as CV, which designates observations made without filter (clear) but using V magnitudes for the comparison stars, the result will be closer to V but will vary depending on the sensitivity of the observer's setup and the star's color.

The overall quality of the photometry, that is its precision, is expressed computing the standard deviation from the mean over the entire night of the difference between the differential magnitude of the Reference star and the Check star. This value is on average about 0.01 magnitude.

Once photometric analysis was completed, a search through the main sky surveys which covered that area was done. The most useful surveys were ASAS-3, CRTS, and NVSV. Since images during these surveys had been taken with different photometric filters, it was mandatory to set a constant zero-point to fit all the available data. Since the main elements presented in this work are independent of absolute magnitude, we decided to shift our data vertically, adding the difference between the average of the survey magnitudes and the average of the differential magnitudes worked out from our images. If data from two or more surveys were available, we used the mean of the larger set.

With all these data merged togheter, PERANSO software was used as the main tool for period analysis using the ANOVA algorithm (Schwarzenberg-Czerny 1996) as well as for period folding. In the end, data for each new variable were added to VSX.

3. Results for individual variables

3.1. GSC 01394-01889

This object was observed unfiltered from December 18, 2014, to January 1, 2015, collecting a total of 272 measurements over 6 nights. Frequency analysis gives an orbital period P = 1.470827 ± 0.00002 days. We show in Figure 1 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with different depths. Data from CRTS were available for this variable and the 689 measurements have been added to the light curve. From its shape, we classified this variable as an eclipsing binary of EA type.

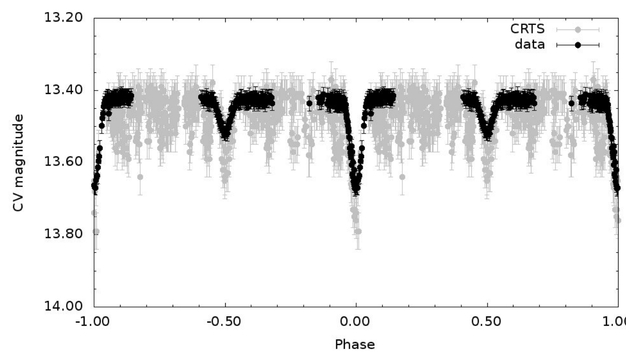

Figure 1. Folded light curve of GSC 01394-01889.

3.2. GSC 00853-00371

This object was observed unfiltered on March 9 and 27, 2015, collecting a total of 122 measurements over 2 nights. Frequency analysis gives an orbital period P = 0.255054 ± 0.00002 day. We show in Figure 2 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with equal depths. Data from CRTS were available for this variable and the 472 measurements have been added to the light curve. From its shape, we classified this variable as an eclipsing binary of EW type.

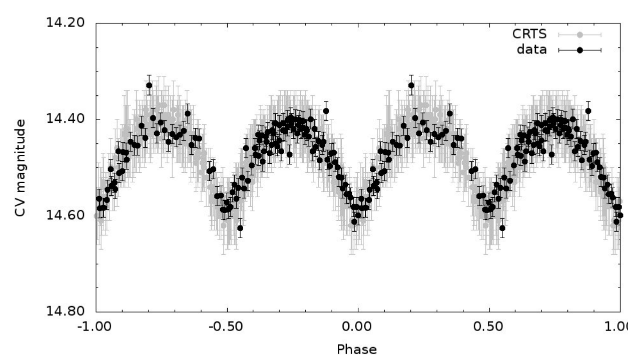

Figure 2. Folded light curve of GSC 00853-00371.

3.3. CSS J171124.7-004042

This object was observed unfiltered from May 28 to June 1, 2015, collecting a total of 314 measurements over 4 nights. Frequency analysis gives an orbital period P = 0.352604 ± 0.00002 day. We show in Figure 3 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with equal depths. Data from CRTS were available for this variable and the 232 measurements have been added to the light curve. From its shape, we classified this variable as an eclipsing binary of EW type.

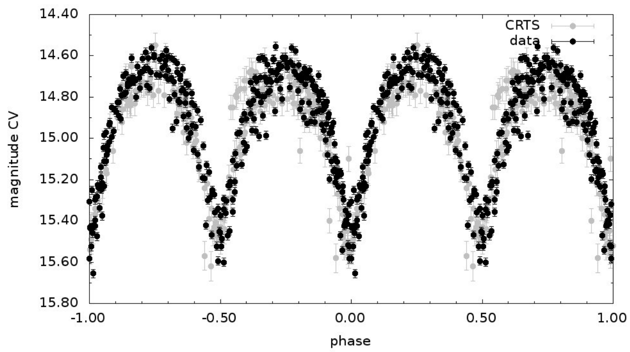

Figure 3. Folded light curve of CSS J171124.7-004042.

3.4. GSC 05065-00218

This object was observed unfiltered from May 12 to June 1, 2015, collecting a total of 596 measurements over 6 nights. Frequency analysis gives an orbital period P = 1.205530 ± 0.00002 days. We show in Figure 4 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with different depths. Data from ASAS-3, CSS, and NSVS were available for this variable and therefore 615 measurements have been added to the light curve. From its shape, we classified this variable as an eclipsing binary of EA type.

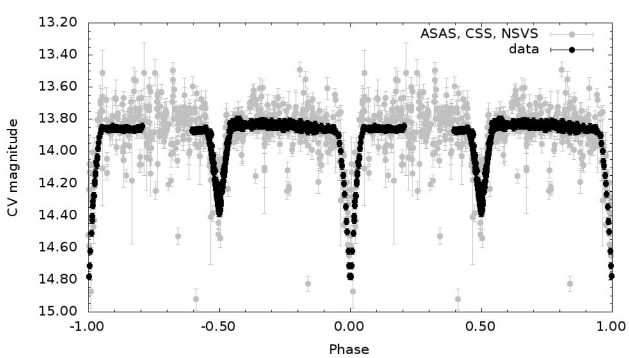

Figure 4. Folded light curve of GSC 05065-00218.

3.5. UCAC4 388-136835

This object was observed unfiltered on July 17, 2015, collecting a total of 51 measurements. Frequency analysis detected a clear sinusoidal-like modulation with a dominant period of 0.465497 ± 0.00002 day. We show in Figure 5 the light curve folded according to the period found. The periodicity and the amplitude of the light curve variations (~1.2 mag. in CV band), as well as its light curve shape, are compatible with those of an RRab, for which the highest frequency represents the principal pulsation mode. Data from CRTS were available for this variable and therefore 81 measurements have been added to the light curve.

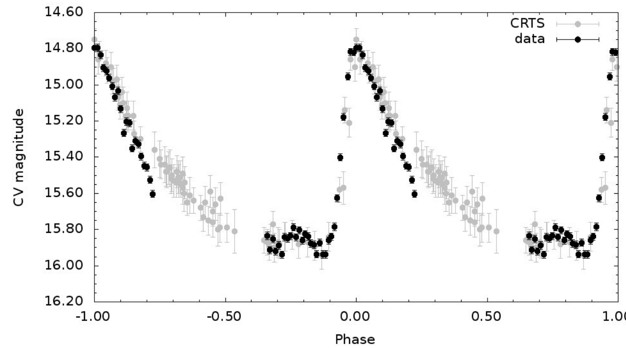

Figure 5. Folded light curve of UCAC4 388-136835.

3.6. UCAC4 386-142199

This object was observed unfiltered on the night of July 14, 2015, for a total of 60 measurements. Frequency analysis gave an orbital period P = 0.319437 ± 0.00002 day. We show in Figure 6 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with equal depths. Data from CRTS are available for this variable and therefore 81 measurements have been added to the light curve. From its shape, we classified this variable as an eclipsing binary of EW type.

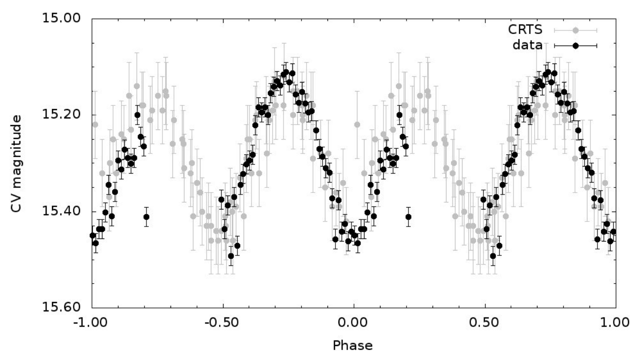

Figure 6. Folded light curve of UCAC4 386-142199.

3.7. 2MASS J20060657-1230376

This object was observed unfiltered on July 14, 2015, collecting a total of 53 measurements. According the 2MASS catalog (Skrutskie *et al.* 2006), this star has J–K = 0.17 (rather blue). From these data, we worked out a color index (V–R) = 0.242 which suggests an F5V spectral type. This is indicative of an RRc variable rather than an EW. Furthermore, the periodicity and the amplitude of the light curve variations (~0.3 mag. in CV band), as well as its light curve shape with shallow minima, are compatible with those of an RRc, for which the highest frequency represents the first overtone pulsation mode. Thus, we can confidently exclude that this object is an eclipsing binary. Frequency analysis detected a clear sinusoidal-like modulation with a dominant period of 0.209923 ± 0.00002 day. We show in Figure 7 the light curve folded according to the period found.

Table 2. Main information and results for the new variables discovered.

Star (VSX identifier)	R. A. (J2000) h m s	Dec. (J2000) ° ′ ″	Constellation	V	Period (days)	Epoch (HJD-2455000)	Type
GSC 01394–01889	09 01 35.89	+15 01 59.3	Cnc	13.65–13.89	1.470827 ± 0.000002	2024.5352 ± 0.0001	EA
GSC 00853–00371	10 59 28.58	+14 39 42.5	Leo	14.42–14.61	0.255054 ± 0.000003	2091.3684 ± 0.0001	EW
CSS_J171124.7–004042	17 11 24.62	–00 40 41.5	Oph	14.67–15.51	0.352604 ± 0.000002	2172.4153 ± 0.0001	EW
GSC 05065–00218	17 12 28.99	–00 41 20.0	Oph	13.84–14.77	1.205530 ± 0.000002	2173.5696 ± 0.0001	EA
UCAC4 388–136835	20 01 46.93	–12 25 04.2	Sgr	14.79–15.93	0.465497 ± 0.000002	2221.5128 ± 0.0001	RRab
UCAC4–386–142199	20 04 55.95	–12 54 35.7	Sgr	15.13–15.46	0.319437 ± 0.000003	2218.5527 ± 0.0001	EW
2MASS J20060657–1230376	20 06 06.57	–12 30 37.7	Sgr	16.02–16.36	0.209923 ± 0.000004	2218.5920 ± 0.0001	RRc
UCAC4 386–142583	20 07 58.91	–12 58 04.4	Cap	14.18–15.28	0.674897 ± 0.000002	2216.390 ± 0.001	RRab
UCAC4 398–127457	20 09 51.08	–10 33 59.7	Cap	15.50–15.82	0.291891 ± 0.000004	2210.4150 ± 0.0001	EW
UCAC4 384–148138	20 09 52.43	–13 15 17.8	Cap	14.44–15.12	0.375792 ± 0.000002	2215.5623 ± 0.0001	EW
UCAC4 398–127590	20 10 45.59	–10 27 45.4	Cap	15.12–15.68	0.309689 ± 0.000003	2210.5549 ± 0.0001	EW
UCAC4–383–155837	20 14 23.91	–13 26 57.7	Cap	16.25–16.70	0.437581 ± 0.000002	2202.5222 ± 0.0001	EA
GSC 05752–01113	20 15 50.47	–14 30 57.2	Cap	14.37–14.81	0.332192 ± 0.000002	2199.4786 ± 0.0001	EW
GSC 05765–01271	20 49 33.29	–12 08 51.6	Aqr	12.89–13.09	0.382878 ± 0.000002	2254.5065 ± 0.0001	EW

Data from CRTS were available for this variable and therefore 143 measurements have been added to the light curve.

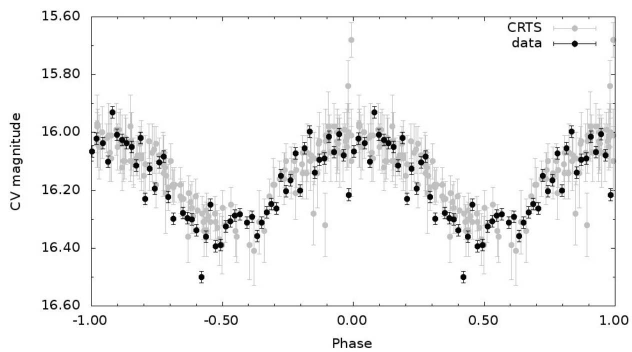

Figure 7. Folded light curve of 2MASS J20060657-1230376.

3.8. UCAC4 386-142583

This object was observed unfiltered on July 12 and 20, 2015, collecting a total of 137 measurements. Frequency analysis detected a clear sinusoidal-like modulation with a dominant period of 0.674897 ± 0.00002 day. We show in Figure 8 the light curve folded according to the period found. The periodicity and the amplitude of the light curve variations (~1.0 mag. in CV band), as well as its light curve shape, are compatible with those of an RRab, for which the highest frequency represents the principal pulsation mode. Data from CRTS were available for this variable and therefore 132 measurements have been added to the light curve. Looking at the survey data, they don't seem to fit exactly with the folded period, suggesting the possible presence of a light curve amplitude distortion which is typically related to the Blazhko effect (Blazhko 1907) in this class of variables.

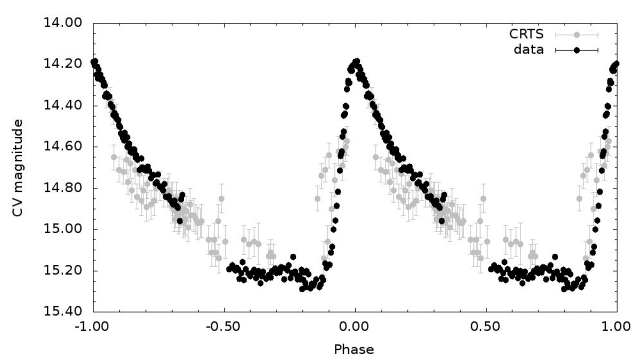

Figure 8. Folded light curve of UCAC4 386-142583.

3.9. UCAC4 398-127457

This object was observed unfiltered on the night of July 7, 2015, for a total of 42 measurements. According to the 2MASS catalog, this star has J–K = 0.55. From these data, we worked out a color index (V–R) = 0.483 which suggests a K0V-K2V spectral type (K0V V–R = 0.45, K2V V–R = 0.52). This is indicative of an EW variable rather than a pulsating one. Frequency analysis gave an orbital period P = 0.319437 ± 0.00002 day. We show in Figure 9 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with equal depths. Data from CRTS are available for this variable and therefore 135 measurements have been added to the light curve.

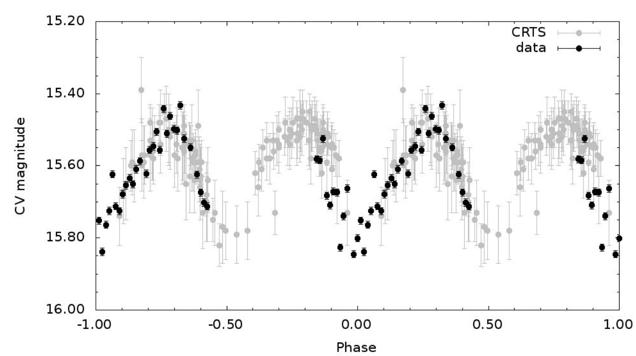

Figure 9. Folded light curve of UCAC4 398-127457.

3.10. UCAC4 384-148138

This object was observed unfiltered on the night of July 11, 2015, for a total of 68 measurements. Frequency analysis gave an orbital period P = 0.375792 ± 0.00002 day. We show in Figure 10 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with equal depths. Data from CRTS are available for this variable and therefore 107 measurements have been added to the light curve. From its shape, we classified this variable as an eclipsing binary of EW type.

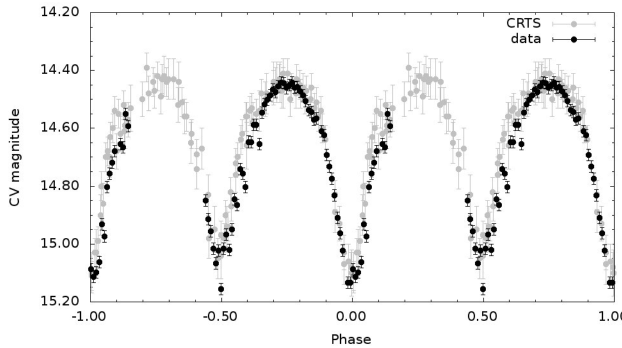

Figure 10. Folded light curve of UCAC4 384-148138.

3.11. UCAC4 398-127590

This object was observed unfiltered on the night of July 7, 2015, for a total of 62 measurements. Frequency analysis gave an orbital period P = 0.309689 ± 0.00002 day. We show in Figure 11 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with equal depths. Data from CRTS are available for this variable and therefore 135 measurements have been added to the light curve. From its shape, we classified this variable as an eclipsing binary of EW type.

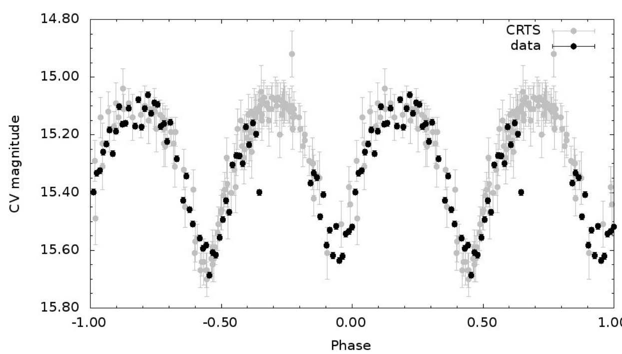

Figure 11. Folded light curve of UCAC4 398-127590.

3.12. UCAC4 383-155837

This object was observed unfiltered from June 28 to July 10, 2015, collecting a total of 139 measurements over 3 nights. Frequency analysis gave an orbital period P = 0.437581 ± 0.00002 day. We show in Figure 12 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with different depths. Data from CRTS were available for this variable and therefore 181 measurements have been added to the light curve. From its shape, we classified this variable as an eclipsing binary of EA type.

3.13. GSC 05752-01113

This object was observed unfiltered on the night of June 25, 2015, for a total of 48 measurements. Frequency analysis gave an orbital period P = 0.332192 ± 0.00002 day. We show in Figure 13 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with equal depths. Data from ASAS and CRTS are available for this variable and therefore 369 measurements have been added to the light curve. From its shape, we classified this variable as an eclipsing binary of EW type.

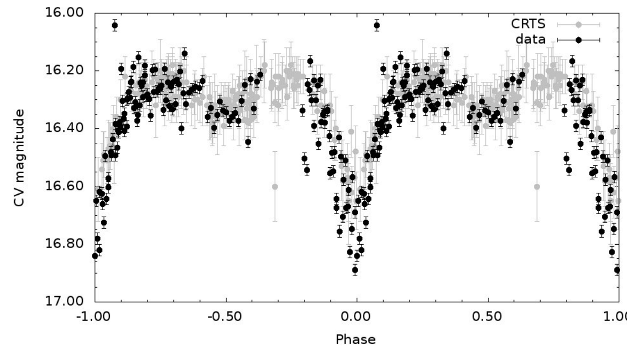

Figure 12. Folded light curve of UCAC4-383-155837.

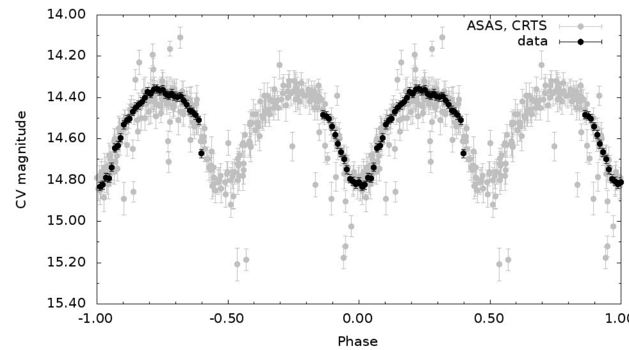

Figure 13. Folded light curve of GSC 05752-01113.

3.14. GSC 05765-01271

This object was observed unfiltered from August 19 to September 9, 2015, for a total of 218 measurements. Frequency analysis gave an orbital period P = 0.382878 ± 0.00002 day. We show in Figure 14 the light curve folded according to the period found, which clearly reveals the presence of a primary and a secondary minimum with equal depths. Data from CRTS are available for this variable and therefore 467 measurements have been added to the light curve. From its shape, we classified this variable as an eclipsing binary of EW type.

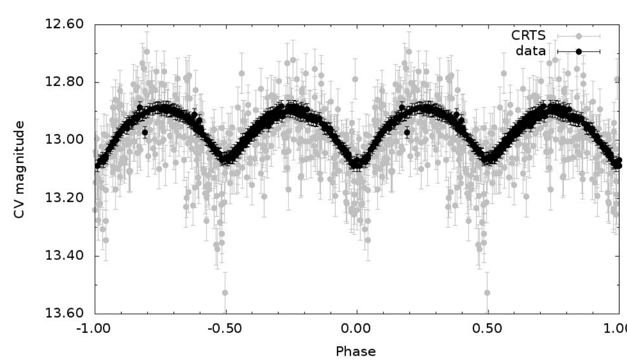

Figure 14. Folded light curve of GSC 05765-01271.

4. Conclusions

After having observed asteroids for about one year for the purpose of doing photometry and plotting their light curves, we have collected thousands images, many of which are centered all night on the same field. Doing a variable star search in these fields allowed us to discover 14 new variable stars—11 eclipsing binaries and 3 short period pulsators of RR Lyrae class. The details of each of the 14 stars are given in Table 2 in order of increasing Right Ascension. Phase plots for all these stars are shown in Figures 1 through 14 in section 3.

5. Acknowledgements

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We also want to thank Mike Foylan for his proposal of the target GSC 05065-00218 whose variability he had discovered in 2011 and asked our collaboration for following it up and data analysis. We gladly thank here Brian Warner, Director of the Palmer Divide Observatory, who kindly helped us following up the same star from Colorado.

This work has made use of the VizieR catalog access tool, CDS, Strasbourg, France, the ASAS catalog, the CRTS catalog, the NSVS catalog, and of course the International Variable Star Index (VSX) operated by the AAVSO.

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