LIGHTCURVE ANALYSIS FOR FOUR NEAR-EARTH ASTEROIDS

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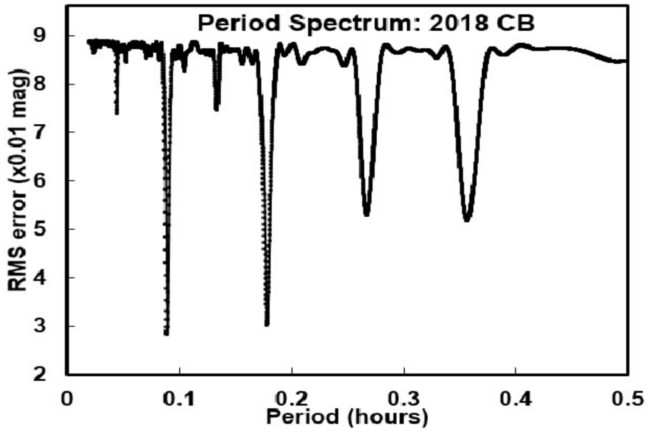
Lightcurves for four near-Earth asteroids observed from Great Shefford Observatory during close approaches in 2018 and 2020 are reported: 2018 CB, 2018 GE3, 2020 KK7 and 2020 SW. All are small (H > 23) fast or super-fast rotators.

Photometric observations of near-Earth asteroids during close approaches to Earth in 2018 and 2020 were made at Great Shefford Observatory using a 0.40-m Schmidt-Cassegrain and Apogee Alta U47+ CCD camera. All observations were made unfiltered and with the telescope operating with a focal reducer at f/6. The 1K×1K, 13-micron CCD was binned 2×2 resulting in an image scale of 2.16 arcsec/pixel. *Astrometrica* (Raab, 2018) was used to measure photometry using APASS Johnson V band data from the UCAC4 catalogue and *MPO Canopus* (Warner, 2018; 2020), incorporating the Fourier algorithm developed by Harris (Harris et al., 1989) was used for lightcurve analysis.

2018 CB. This small Apollo object was discovered on 2018 Feb 4 (Fuls et al., 2018), 5 days before making a very close approach to Earth, at ~70,000 km, or 0.18 Lunar Distances on 2018 Feb 9 22:28 UT. It was tracked from Great Shefford for 3.5 hours, from 18:01 UT to within an hour of closest approach and its proximity posed some challenges. The apparent rate of motion increased from 400 to over 1,200 arcsec/min, so exposures were limited initially to 1.0 s, reducing down to 0.4 s by the end. The phase angle increased from 68° to 114° and this caused the amplitude of light variations to increase very rapidly, especially at the end of the observing period. 2018 CB moved across 48° of sky and this necessitated the telescope being repositioned 116 times. A total of 1,841 images were measured and imported into Canopus as 116 separate sessions, but due to the increasing lightcurve amplitude only the first 38 (covering 90 minutes) have been used here to derive a lightcurve. The apparent mag was +12 - +13 throughout. A search of the Asteroid Lightcurve Database (LCDB; Warner et al., 2009) and wider searches did not find any previously reported results for 2018 CB.

The period spectrum favours an asymmetric bimodal solution with period 0.089241 h but a quadrimodal solution also appears to be a possibility, with relatively small amplitude (0.24) at high phase angle (67° - 80°). But a split-halves diagram using double the bimodal period shows the two halves to be essentially the same so the bimodal solution is assumed correct in this analysis.

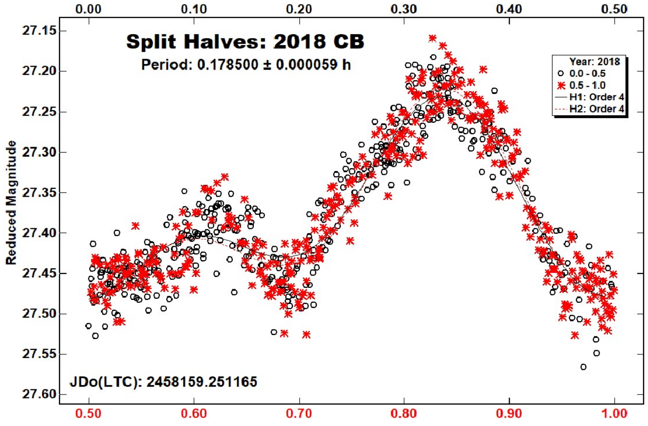
Small adjustments to the zero-points of the sessions were made to minimize the overall RMS fit of the lightcurve, the largest adjustment being 0.07 mag and the RMS for all adjustments was 0.03 mag.

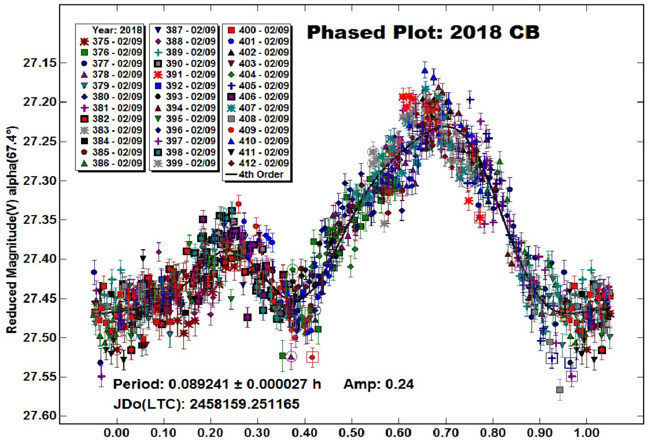


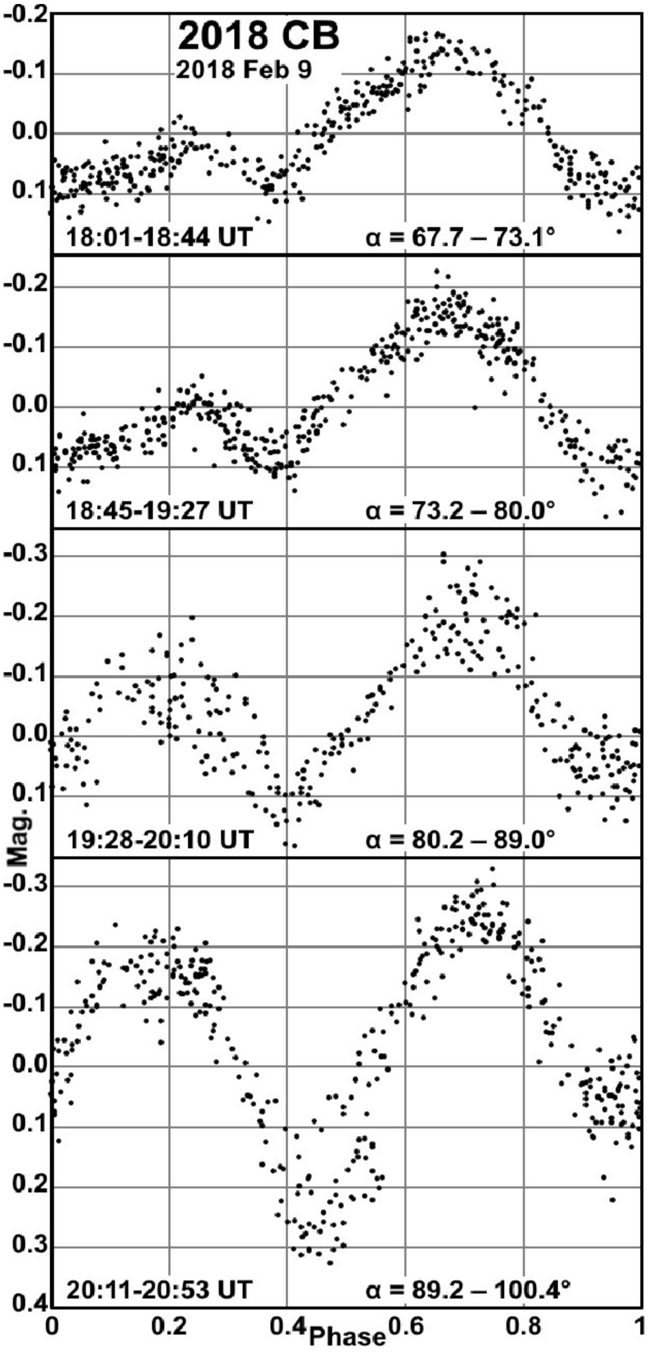
The remaining 78 sessions show a similar period when analysed with Canopus, but with lightcurve features rapidly increasing in size. The coefficients from the 4th order Fourier solution generated for the phased lightcurve plot were used to model the lightcurve for all available data points. Phased plots of relative magnitude for four separate periods, to illustrate the amplitude changes are given, together with a plot of the Amplitude vs Phase Angle relationship, horizontal bars indicating the range of phase angles included in each amplitude determination.

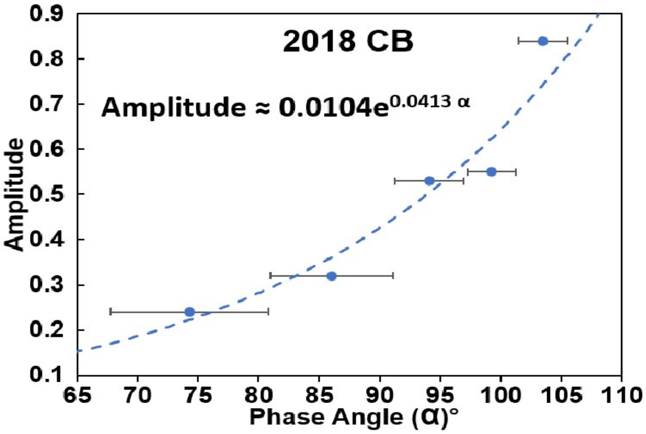
It is not possible to determine what contributions phase angle or changing 'pole-on' geometry contributed, but an empirical formula approximating the observed non-linear Amplitude / Phase Angle relationship in the range 68° < α < 106° is:

$$\text{Amplitude} \approx 0.0104\, e^{0.0413\,\alpha}$$



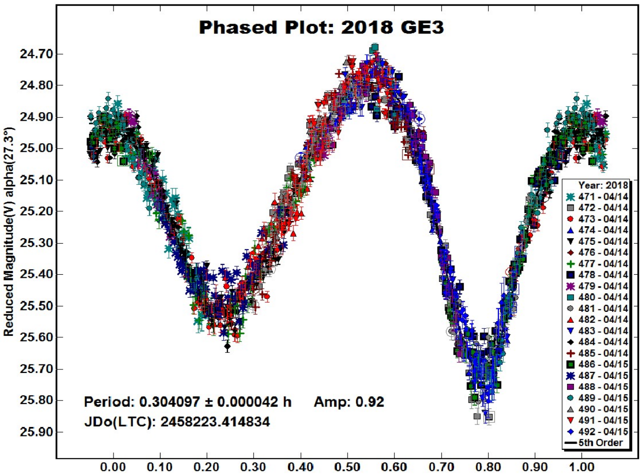






2018 GE3. An Apollo object discovered on 2018 April 11 (Tichy et al., 2018) and making a close approach to Earth on 2018 April 15.28 UT was followed from 21:57-01:16 UT on the night of 2018 April 14/15 as it brightened to apparent mag ≥+13. Distance from Earth decreased from 940,000 to 602,000 km during that period and because of the large apparent rate of motion (77, increasing to 187 arcsec/min) exposures were reduced from 5 s down to 2 s to ensure the trail was always enclosed in a 3-pixel radius annulus in Astrometrica. The telescope was repositioned 22 times and 1274 images were obtained. Measurements made in Astrometrica were imported into 22 sessions within Canopus and small adjustments to the zero-points of the sessions were made to minimize the overall RMS fit of the lightcurve, the largest adjustment being 0.13 mag and the RMS for all adjustments was 0.06 mag. A bimodal solution of 0.304097 ± 0.000042 h with amplitude of 0.92 mag indicates that 10.9 revolutions of 2018 GE3 occurred during the 3 h 19 min it was under observation.

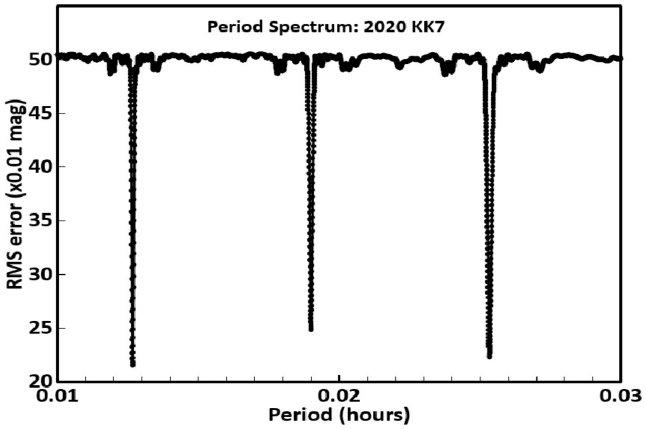
A search of the LCDB provides one previously reported lightcurve (Gornea et al., 2018), from observations covering 2018 April 14 22:44–23:43 UT, entirely within the period observed from Great Shefford and with P = 0.304 h and A = 0.93 mag agrees very well with the solution determined here.



2020 KK7. This Apollo object was discovered on 2020 May 25 (Bulger et al., 2020a) and was only brighter than18 mag on 2 nights before passing Earth at 1.3 Lunar Distances on 2020 June 2.4 UTC. A search of the LCDB and wider searches do not reveal any previously reported lightcurve results. 2020 KK7 was observed from Great Shefford on 2020 May 31 at the start and end of the night for astrometry purposes (runs 1 & 2 in Table 1), then again on 2020 June 01 at start and end of the night for astrometry (runs 3 & 5) and also during a 43-min period in between, specifically for photometry (run 4).

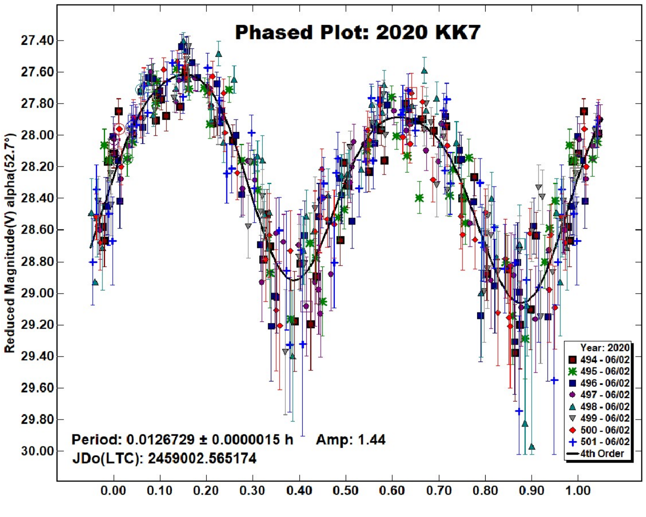
Run	2020 May/June dd hh:mm -dd hh:mm	Fields/ Points	Phase range	Exp
1	31 22:36-31 22:58	2/69	23.6-23.7	10,8
2	01 00:47-01 00:57	1/58	24.3	6
3	01 21:50-01 22:07	4/202	42.8-43.4	1
4	02 01:34-02 02:17	8/368	52.5-54.9	3.8,2.4
5	02 02:19-02 02:27	2/118	55.0-55.5	1

Table I. Summary of observing runs. The start and end times of images used is given. Fields/Points gives the number of times the telescope was repositioned to different fields during the run together with the number of data points used in the analysis. Phase range gives the phase at start and end of each run. Exp is the exposure times in seconds used during the runs



2020 KK7 was 18th mag on the first night and 16th mag on the second but on both nights large variations in magnitude were evident between consecutive exposures. On the first night the object was too faint to see on individual exposures at minimum, but on the second night it was visible throughout its light variations. As the object approached the Earth on the second night the apparent speed exceeded 200 arcsec/min and exposures were limited to less than 4 seconds to keep the trails short enough to measure with a 3-pixel radius annulus in Astrometrica. The 368 measures obtained during run 4 involved the telescope being repositioned 8 times due to the fast motion of the object and these measures were imported into Canopus. The resulting period spectrum indicates a bimodal solution is marginally preferable but is also suggested from the large amplitude (Harris et al., 2014), though the large phase angle will have enhanced the observed amplitude and made this inference somewhat less conclusive.

Small adjustments to the zero-points of the 8 sessions were made to minimize the overall RMS fit of the lightcurve, the largest adjustment was 0.1 mag and the RMS for all adjustments was 0.06 mag. With a period of 45.6 s, 2020 KK7 completed 57 revolutions during the 43 minutes of run 4.

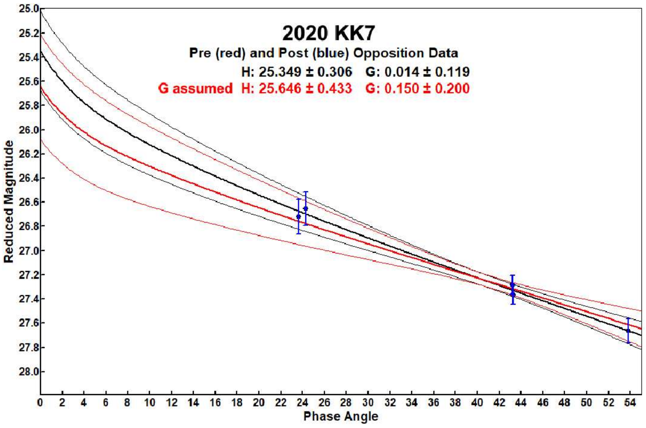


Measurements obtained from the start of run 3 and the end of run 5 were affected by twilight and have not been used in the analysis but runs 1, 2 and the latter half of run 3 were measured and the peak brightness values selected and combined with the peak brightness from the lightcurve produced from run 4 to plot an H-G diagram which gives H_V = 25.35 ± 0.31, G = 0.01 ± 0.12. Assuming a value of G = 0.15 results in H_V = 25.65.

The JPL Small-Body Database Browser (JPL, 2020) gives H = 26.328 ± 0.293 assuming G = 0.15 and as this is calculated from photometry submitted with astrometry to the Minor Planet Center taken with a variety of exposure lengths it can be regarded as being derived from the average brightness of the lightcurve, especially due to the short 46-s rotation period. The value of H_V with assumed G=0.15 determined here for the peak magnitude can be adjusted by half the amplitude to give an average brightness figure, i.e.

$$H_v \text{ (average mag)} = 25.65 + 0.72 = 26.37$$

and this is in good agreement with the JPL value.

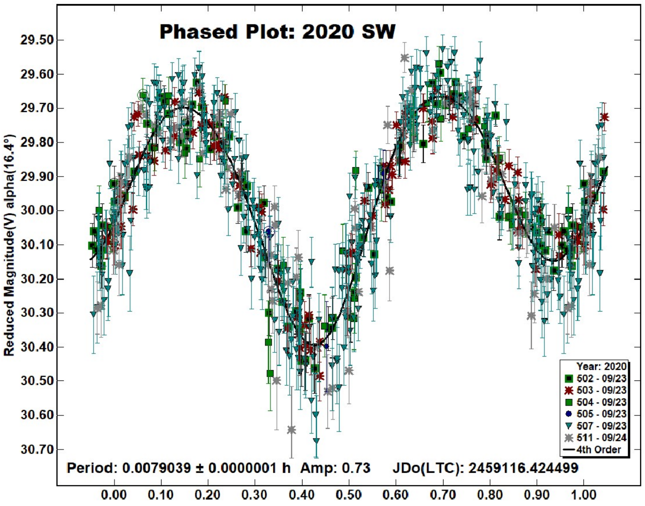


2020 SW. Notable for a very close approach to 21,700 km from the Earth's surface on 2020 Sep 24.47 UT, this small Apollo object was discovered by Kacper Wierzchoś (Bulger et al., 2020b) and for such a small object with the unusually long lead-time of nearly 7 days before its passage. It was observed at Great Shefford to within 10 hours of close approach when it was well within the orbit of the Moon, though its sky motion was not excessive (50 arcsec/min) as it headed almost directly toward Earth. The apparent mag was ≥16 throughout the period of observation and exposures as long as 15 s were possible without excessive trailing, but as large brightness variations were obvious between trial exposures taken 6 s apart the decision was made to limit exposures to 4 s or less to capture any superfast rotation present. Exposures of 4, 2 and 1 seconds were taken, but the 1 second exposures were not used in this analysis due to the larger noise in measurements. The longer, 4 s exposure length, at 0.14 * Period (P) is below the $0.185P$ threshold where a reduction in strength of the lightcurve's 2nd harmonic and smoothing of the lightcurve would become problematic, due to the derived very short 28.5 second rotation period (Pravec et al., 2000). As with the other analyses here, small zero-point adjustments to the six sessions were made to minimise the overall RMS fit of the lightcurve, the largest adjustment was 0.05 mag and the RMS for all adjustments was 0.03 mag. 2020 SW completed 362 revolutions during the 2 h 51 min elapsed time used to produce the lightcurve.

Number	Name	Intg. time	Intg. / Period	Min a/b
	2018 CB	1.0	0.003	1.1
	2018 GE3	4.9	0.004	1.6
	2020 KK7	3.8	0.083	1.7
	2020 SW	4.0	0.14	1.6

Table II. Ancillary information, listing the longest integration time used (seconds), the fraction of the period represented by the integration time (see Pravec et al., 2000) and the calculated minimum elongation of the asteroid (Kwiatkowski et al., 2010).

A search of the ADS (2020) and the LCDB did not find any previously reported results but a preliminary result published on Twitter (Wells and Bamberger, 2020) of P = 0.00790 ± 0.00001 h, Amp = 0.72 agrees well with this analysis.



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Number	Name	yyyy mm/ dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E	Grp	H
	2018 CB	2018 02/09-02/09	67.7,103.5	107	17	0.089241	0.000027	0.24	0.05	NEA	25.9
	2018 GE3	2018 04/14-04/14	27.4,33.9	217	9	0.304097	0.000042	0.92	0.05	NEA	23.8
	2020 KK7	2020 05/31-06/02	23.6,55.5	248	19	0.0126729	0.0000015	1.44	0.10	NEA	26.3
	2020 SW	2020 09/23-09/24	16.4,14.8	5	7	0.0079039	0.0000001	0.73	0.07	NEA	29.1

Table III. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009) and H is the absolute magnitude at 1 au from Sun and Earth taken from the SBDB (JPL, 2020).