

**LIGHTCURVE ANALYSIS FOR
341 CALIFORNIA, 594 MIREILLE, 1115 SABAUDA,
1504 LAPPEENRANTA, AND 1926 DEMIDDELAER**

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Synodic rotation periods were determined for five main-belt asteroids: 341 California, 317 h with suspected tumbling; 594 Mireille, 4.9671 ± 0.0004 h; 1115 Sabauda, 6.7165 ± 0.0007 h; 1504 Lappeenranta, 15.16 ± 0.01 h; and 1926 Demiddeleer, 32.095 ± 0.027 h. All the data have submitted to the ALCDEF database.

CCD photometric observations of five main-belt asteroids were performed at Command Module Observatory (MPC V02) in Tempe and the Lowell Observatory Anderson Mesa Station (MPC 688) outside Flagstaff. Images at V02 were taken using a 0.32-m *f*/6.7 Modified Dall-Kirkham telescope, SBIG STXL-6303 CCD camera, and either a Cousins R or ‘clear’ glass filters. Exposure times for all the images were 3 minutes. The image scale after 2x2 binning was 1.76 arcsec/pixel. Images taken at 688 employed the 0.7-m *f*/8 telescope, which has a CCD camera system designed and built in the Lowell instrument shop (Buie, 2010). The image scale was 0.91 arcsec/pixel with 2x2 binning. Either Johnson V or Cousins R filters were used for the asteroid observations. Table I shows the observing circumstances and results.

The V02 images were calibrated using a dozen bias, dark, and flat frames. Flat-field images were made using an electroluminescent panel. The 688 data made use of 20 full-frame biases and 15 or more twilight flats taken each night under an automated exposure routine with the telescope aimed at the ‘Chromey spot’ (Chromey et al., 1996), tracked at the sidereal rate but dithered 30" between frames. The thinned, back-illuminated e2v CCD was kept at roughly -110° C using a Cryotiger chiller and so had negligible dark current.

The data reduction and period analysis were done using *MPO Canopus* (Warner, 2017). The asteroid and three to five comparison stars were measured, preserving comp stars among adjacent nights if possible (more readily done with the 45'x30' field of the V02 CCD). We attempted to keep the comparison star colors within the range roughly $0.5 < B-V < 0.95$, or equivalent ‘asteroidal’ color-ranges in other photometric systems, though this was not always possible. In order to reduce the internal scatter in the data, we typically chose the brightest stars of appropriate color that had peak ADU counts below the range where chip response becomes nonlinear in both cameras.

Although the *MPO Canopus* internal star catalogue helped in selecting comp stars, we adopted magnitudes from a combination of CMC15 (Muñoz et al. 2014), APASS DR9 (Munari et al. 2015), GAIA1 G magnitudes (Sloan $r' = G + 0.066$ for stars of asteroidal color), as well as the original SDSS DR7 (Abazajian et

al., 2009) and Pan-STARRS (Magnier et al., 2016) catalogues (for faint stars only) to set the zero-points each night. This process took into consideration the number of nights of measurement and the internal scatter reported in the catalogues. We also checked for obvious variables in the TASS MkIV survey (Droege et al., 2006) and in VSX (Watson et al., 2006). For V-band photometry the ASAS-3 (Pojmanski 2002) catalogue was also queried. These data were found using the CDS VizieR catalogue-query service (VizieR, 2017), the ASAS-3 query page, and the Pan-STARRS search page at the Space Telescope MAST archive. In most regions the Sloan r' data sources for brighter stars yielded very similar magnitudes (within about 0.05 mag total range), so we took mean values rounded to 0.01 mag precision. We usually adopted only the higher-accuracy Pan-STARRS or SDSS DR7 data for stars fainter than about $r' = 13.5$ and 15.0, respectively.

This careful adjustment of the comp star magnitudes and color-indices allowed the separate nightly runs to be linked often with no zero-point offset required, or shifts of only a few hundredths of a magnitude in a series.

Nearly always we used 9-pixel (16 arcsec) diameter measuring apertures for the V02 data. The apertures used on the 0.7-m data varied depending on seeing, but were typically 13 or 15 pixels (12 or 14 arcsec) diameter. When necessary we made use of the *MPO Canopus* ‘Star-B-Gone’ feature to subtract the effects of contaminating field stars, usually successfully. For most of the asteroids described here, we note the RMS scatter on the phased lightcurves, which gives an indication of the overall data quality including errors from the calibration of the frames, measurement of the comp stars, the asteroid itself, and the actual period-fit.

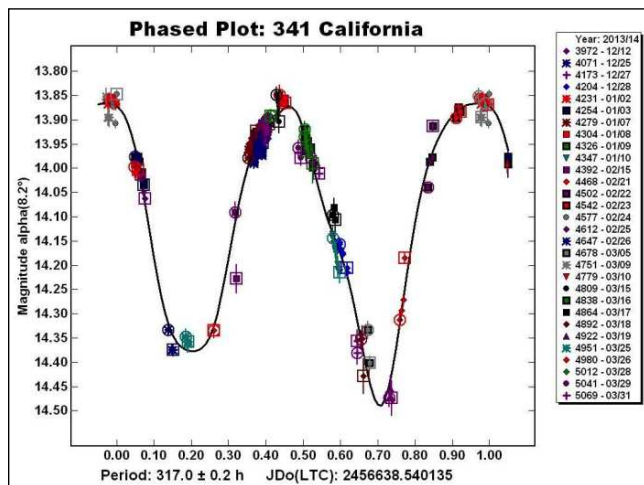
The uncertainties on the period-determination are from the *MPO Canopus* Fourier-type FALC fitting method (cf. Harris et al., 1989). It is worth noting that recently Dykhus et al. (2016, their Appendix B) have checked the reliability of the error estimates resulting from the FALC method, and find from Monte Carlo tests that they are realistic one-sigma errors.

The Asteroid Lightcurve Database (LCDB; Warner et al., 2009) was consulted to locate previously published results. Finally, we note that all our new data are deposited in the ALCDEF database.

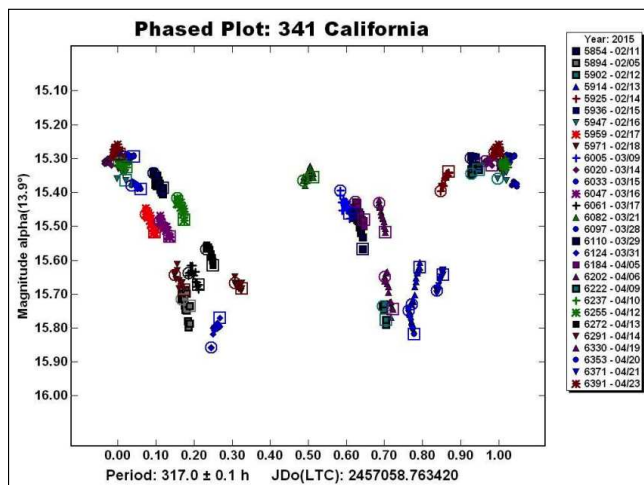
341 California. This Flora-family asteroid was discovered in 1892 by Max Wolf at Heidelberg. Due to its slow rotation, the correct period was poorly determined until recently. Behrend (2005) first reported a period of 8.74 ± 0.05 h. This, however, was based on only two isolated nights in 2005; a single follow-up night in 2008 January yielded the same erroneous period (Behrend, 2008). Skiff (2014) reported a preliminary result, to be described below, showing the period to be nearly two weeks long. More recently Pilcher et al. (2017) acquired an excellent, uniform six-month series in the second half of 2016. This allowed them to confirm that the principal rotation period near 317 h reported by Skiff was correct, and to identify a secondary ‘tumbling’ period of some 250 h.

The asteroid was followed from 2013 December through 2014 March at Lowell using the LONEOS 0.55-m *f*/1.9 Schmidt camera (MPC 699) for the first two nights only (unfiltered), and then the 0.7-m telescope (Rc filter) in robotic mode for the remaining 28 nights. Since the period was clearly going to be long, data were obtained on several discrete visits each night rather than making continuous runs, similar to what Pilcher et al. have done. The resulting lightcurve showing a period of 317 hours was posted to the CALL site (Skiff 2014). At the time the data were reduced

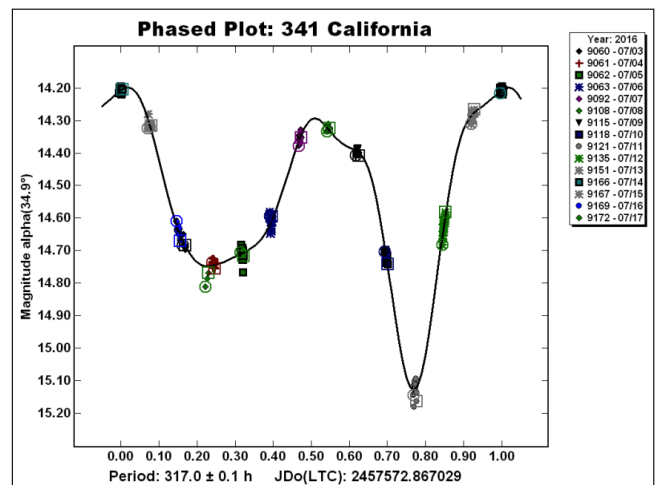
approximately to the Sloan r' system, which has now been revised for both telescopes using more recent photometric catalogues. The first phased plot shows the data from the 2014 apparition with an order-6 fit. The correction to the magnitudes of the comp stars reduces the observed brightness range to 0.58 mag. (originally 0.75 mag.).



Another series using the 0.7-m telescope and V filter was obtained the following year, 2015 Feb-Apr. The data were adjusted as closely as possible to standard Johnson V magnitudes. The lightcurve for this apparition shows much stronger effects from tumbling. The second phased plot is a force-fit to the 317-hour period, where the tumbling effects are obvious. The brightness range is about 0.54 mag.



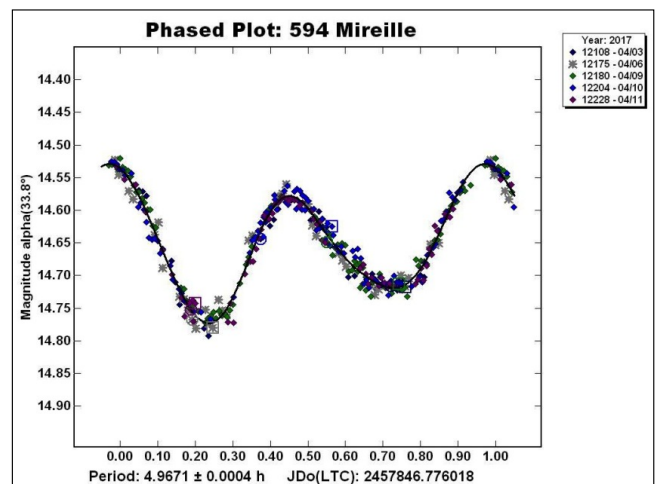
Taking advantage of anomalously clear summer weather in the Southwest US, a third run of 656 data points was acquired at V02 on fourteen consecutive nights beginning on 2016 July 3. The data thus cover just one cycle. Again we show a force-fit to the 317 h period. The data, taken mainly in groups of three 3-minute exposures, are binned here into 10-minute means. The magnitude scale is Sloan r' and the full amplitude is 0.92 mag. at this higher phase angle.



Three additional isolated nights in 2016 were obtained at V02 and at 688 to seek short-period variations (*cf.* Warner, 2016). Like Pilcher *et al.*, we found none. These are included in the ALCDEF files.

594 Mireille. This asteroid was discovered in 1906, also by Max Wolf at Heidelberg. The orbit has moderately high inclination and eccentricity. The only previous period determination was by Wisniewski (1991), who found a period of 4.966 h and an amplitude of 0.18 mag from observations in early 1988.

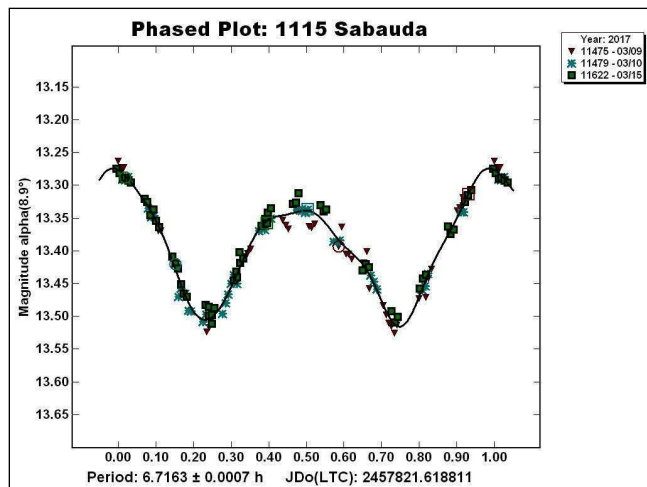
We obtained 352 data points from both V02 and 688 on five nights in 2017 April with the asteroid at $+50^\circ$ ecliptic latitude, well north in the morning sky. All data were reduced to Sloan r' . These yielded a rotation period of 4.9671 ± 0.0004 h, in excellent agreement with Wisniewski's period. The lightcurve morphology is similar to that of Wisniewski. The full amplitude is 0.25 ± 0.01 mag; the RMS scatter on the order-4 fit shown in the phased plot is 0.012 mag.



1115 Sabauda. This outer main-belt asteroid was discovered in 1928 by Luigi Volta at Pino Torinese. Four similar rotational periods have been published. Warner (2006) obtained a period of 6.72 ± 0.01 h. Behrend (2005) and Behrend (2015) show results of 6.75 ± 0.01 h and 6.66 ± 0.02 h, respectively. Finally, Ruthroff (2013) shows a period of 6.72 ± 0.01 h.

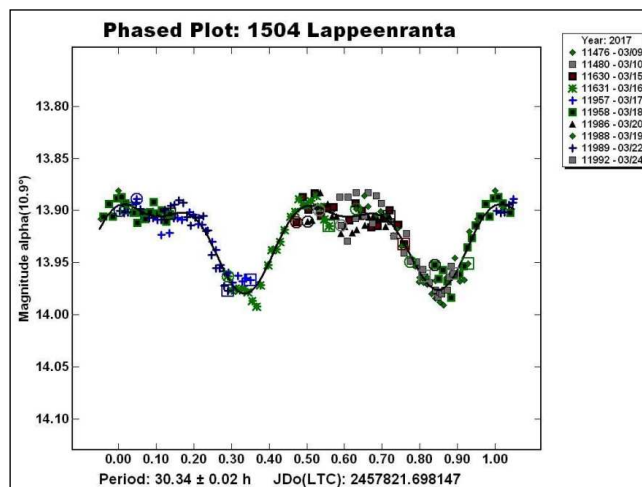
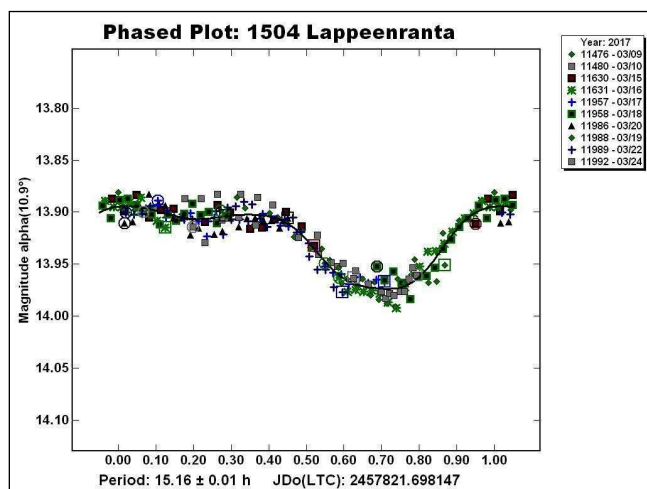
Sufficient data to produce a lightcurve for 1115 Sabauda was secured on three nights at V02 in 2017 March. From 146 data-

points we find a period of 6.7165 ± 0.0007 h, in close agreement with the previous results. The phased plot shows an order-6 fit, which has a full amplitude of 0.22 ± 0.01 mag, and RMS scatter of 0.011 mag.



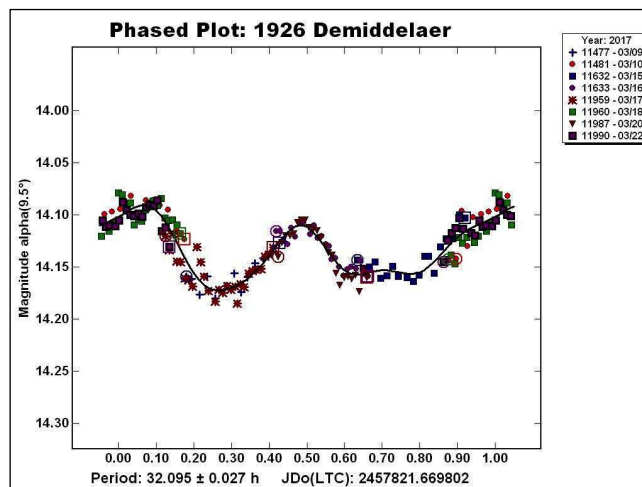
1504 Lappeenranta. This is an inner main-belt asteroid, discovered by Liisi Oterma at Turku in 1939. The LCDB shows four disparate rotational periods with the highest 'U' value only 2+. Binzel (1987) published a period of 10.44 ± 0.10 h and amplitude 0.29 mag from just sixteen measurements on three consecutive nights at McDonald Observatory. Results from Behrend (2002, 2006) are given approximately as 8 h. Most recently Garlitz (2013) derived a period of 15.190 ± 0.009 h and amplitude 0.22 mag.

A total of 637 images from ten nights at V02 in 2017 March were used to determine the period of rotation of 1504 Lappeenranta. Both single and double-mode fits produced acceptable solutions. We therefore show two phased lightcurves, one for 15.16 ± 0.01 h and 30.34 ± 0.02 h. Both plots have the groups of 3 x 3-minute exposures averaged into 10-minute bins. While the single-mode period agrees with Garlitz, the lightcurve morphology differs significantly. The amplitude during 2017 March was only 0.09 $\pm$ 0.01 mag, and the RMS scatter on both fits is 0.009 mag.



1926 Demidellaer. This Eunomia-family asteroid was discovered by Eugène Delporte at Uccle in 1935. Only one period determination has been published, that of Behrend (2008), who computed 18.5 ± 0.3 h.

During eight nights in 2017 March, 525 images of 1926 Demidellaer were acquired at V02. An unambiguous period of 32.095 ± 0.027 h was computed from these, which differs substantially from the previously published one. The phased plot shows an order-5 fit to the data binned into 10-minute averages. The amplitude is again small, only 0.08 ± 0.01 mag, and the RMS scatter on the fit is 0.010 mag.



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Number	Name	20yy/mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period (h)	P.E.	Amp	A.E.	Obs
341	California	13/12/12-14/03/31	1284	8.3, 24.4, 22.0	77	5	317.0	0.2	0.58	0.03	BS
341	California	15/02/11-15/04/23	375	21.8, 2.1, 17.4	173	4	317.0	0.1	0.54	0.03	BS
341	California	16/07/03-16/07/17	656	34.9, 34.1	355	-5	317.0	0.1	0.92	0.03	TP
594	Mirelle	17/04/03-17/04/11	352	33.8, 33.7	165	20	4.9671	0.0004	0.25	0.01	TP, BS
1115	Sabauda	17/03/09-17/03/15	146	8.9, 9.5	235	42	6.7163	0.0007	0.22	0.01	TP
1504	Lappeenranta	17/03/09-17/03/24	637	10.9, 9.9, 10.5	177	16	15.16	0.01	0.09	0.01	TP
1504	Lappeenranta	17/03/09-17/03/24	637	10.9, 9.9, 10.5	177	16	30.34	0.02	0.09	0.01	TP
1926	Demidelaer	17/03/09-17/03/22	525	9.5, 9.4, 10.4	172	18	32.095	0.027	0.08	0.01	TP

Table I. Observing circumstances and results. The phase angle (α) is given at the start and end of each date range, unless it reached a minimum or maximum, which is then the second of three values. LPAB and BPAB are each the average phase angle bisector longitude and latitude (see Harris et al., 1984). The Obs. column gives the observer.

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