

LIGHTCURVE ANALYSIS OF HILDA ASTEROIDS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 1529 OTERMA AND 17428 CHARLEROI

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New CCD photometric observations of 1529 Oterma were made in 2020 May, leading to a preferred period of 14.317 h. This differs from one of our earlier results by an almost exact 8:5 ratio. The data for 17428 Charleroi from 2020 allowed both 4.8 and 6.0 h periods, which are nearly an exact 5:4 ratio. A review of data from 2016 found an alternate period of 4.793 h but could not formally exclude a solution near 5.99 h, which was the only period possible from the 2017 data. Both cases suggest that rotational aliasing is at play and so make it difficult to find a secure solution.

CCD photometric observations of Hilda asteroids are made at the Center for Solar System Studies (CS3) as part of an ongoing study of this family/group that is located between the outer main-belt and Jupiter Trojans in a 3:2 orbital resonance with Jupiter. The goal is to determine the spin rate statistics of the Hildas and to find pole and shape models when possible. We also look to examine the degree of influence that the YORP (Yarkovsky–O’Keefe–Radzievskii–Paddack) effect (Rubincam, 2000) has on distant objects and to compare the spin rate distribution against the Jupiter Trojans, which can provide evidence that the Hildas are more “comet-like” than main-belt asteroids.

Telescopes	Cameras
0.30-m f/6.3 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Proline 1001E
0.35-m f/11 Schmidt-Cass	SBIG STL-1001E
0.40-m f/10 Schmidt-Cass	
0.50-m f/8.1 Ritchey-Chrétien	

Table I. List of available telescopes and CCD cameras at CS3. The exact combination for each telescope/camera pair can vary due to maintenance or specific needs.

Table I lists the telescopes and CCD cameras that are combined to make observations. Up to nine telescopes can be used for the campaign, although seven is more common. All the cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales ranged from 1.24–1.60 arcsec/pixel. All lightcurve observations were unfiltered since a clear filter can result in a 0.1–0.3 magnitude loss. The exposures varied depending on the asteroid’s brightness.

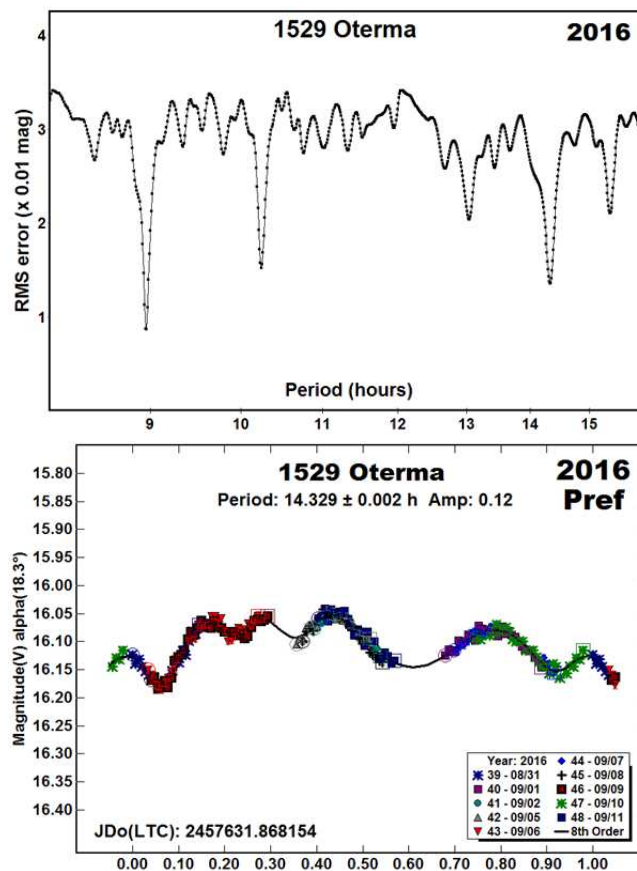
To reduce the number of times and amounts of adjusting nightly zero points, we use the ATLAS catalog r' (SR) magnitudes (Tonry et al., 2018). Those adjustments are usually $\leq \pm 0.03$ mag. The rare greater corrections may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction.

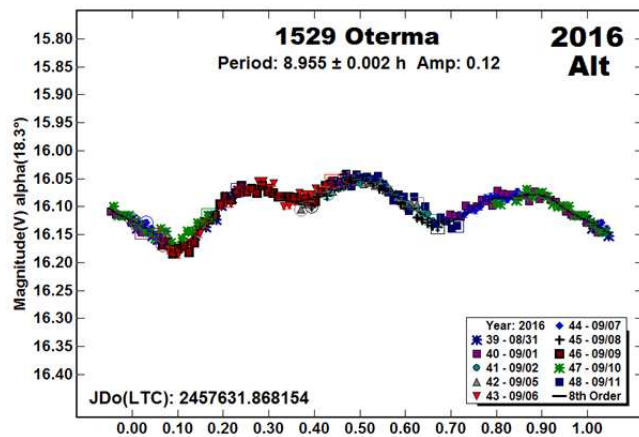
The Y-axis values are ATLAS SR “sky” (catalog) magnitudes. During period analysis, the magnitudes were normalized to the comparison stars used in the earliest session and to the phase angle given in parentheses using $G = 0.15$. The X-axis shows rotational phase from -0.05 to 1.05 . If the plot includes the amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

Our initial search for previous results started with the asteroid lightcurve database (LCDB; Warner et al., 2009) found on-line at <http://www.minorplanet.info/lightcurvedatabase.html>. Readers are strongly encouraged to obtain, when possible, the original references listed in the LCDB. From here on, we’ll use only “LCDB” to reference the paper by Warner et al. (2009).

1529 Oterma. Finding the rotational period for this 6-km Hilda served as a good example of having to deal with *rotational aliasing*, which is when the true number of rotations over the span of the dataset is uncertain. To demonstrate the problem, we present analysis of our datasets from two previous apparitions as well as the most recent one obtained in 2020.

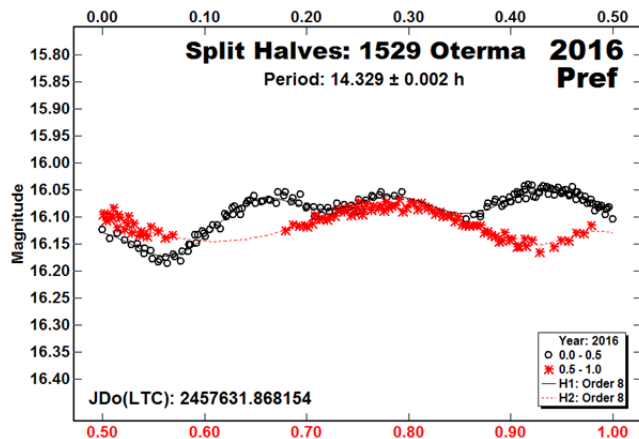
For historical background, Dahlgren et al. (1998) reported a period of 15.75 h based on observations from 1994 Jan 21 – Feb 3. Their bimodal lightcurve had an amplitude of 0.18 mag but covered rotation phase 0.2–0.5 only once and the Feb 3 observations deviated from the phased lightcurve. This indicated that their solution may not have been fully secure.





We first observed Oterma in 2016 (Warner et al., 2017b) and found a period of 8.95 h, which the period spectrum clearly favors. The second-most likely solution near 14.3 h would eventually be what we consider the correct answer. Note that 8th-order Fourier fits were required to have the Fourier model curve closely follow the data.

Looking at the two lightcurves from 2016, the “Alt” solution at 8.955 h would seem the obvious choice. The lightcurve at 14.329 h is incomplete and would often be considered a *fit by exclusion*, i.e., when the Fourier analysis finds a local RMS error minimum by minimizing the number of overlapping data points. This is the interpretation we took when adopting a period of 8.955 h.



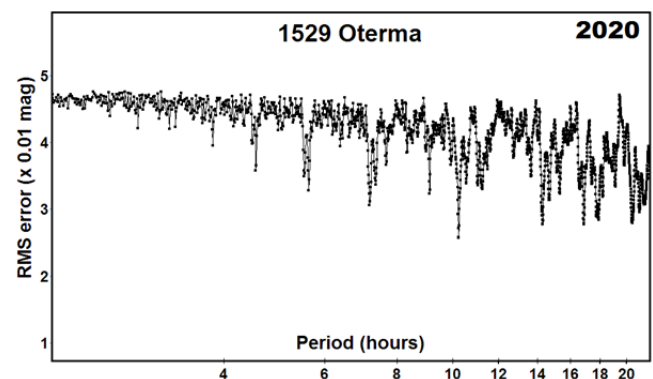
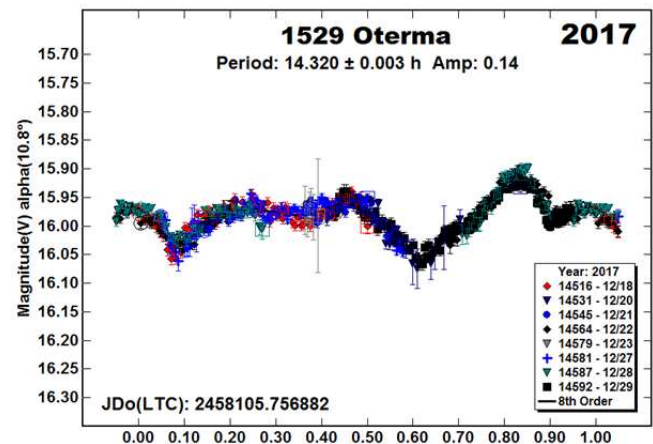
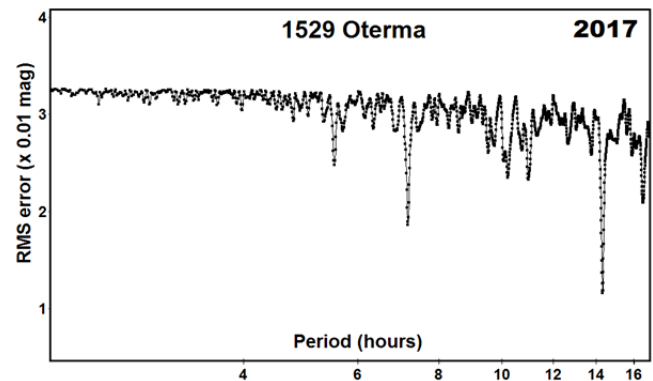
However, when taking another look at the 2016 dataset as part of our analysis of the 2020 dataset, we used a split-halves plot. This plot superimposes the second half of a lightcurve for a given period over the first half (see Harris et al., 2014). If the two halves are nearly symmetrical, especially if within the noise of the data, and the amplitude is $A < \sim 0.20$ mag, the half-period should be given careful consideration. It's clear that the two halves of the 2016 solution for 14.329 h are not symmetrical and so that period, despite the apparent certitude based on the shorter period lightcurve, should be the preferred solution.

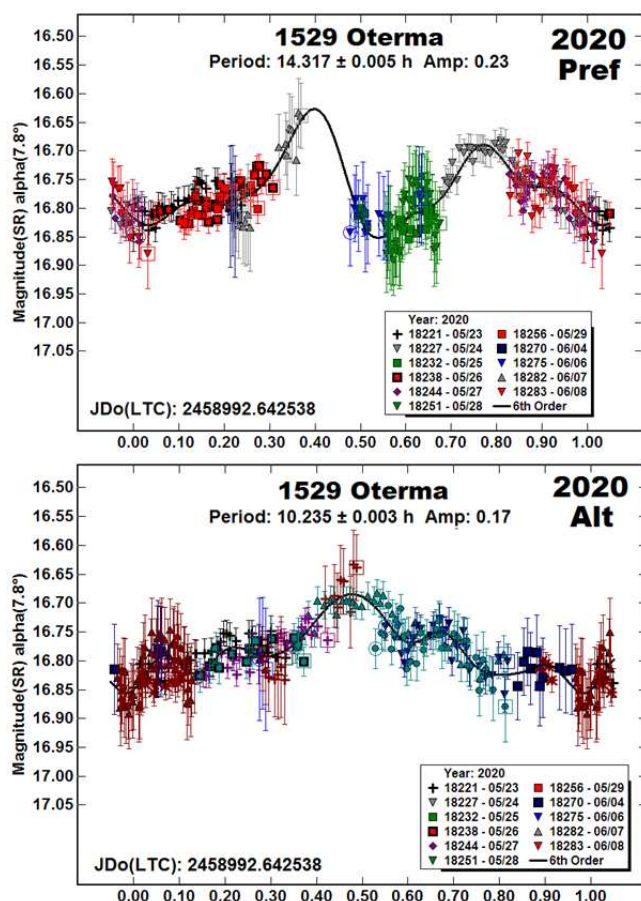
This is where *rotational aliasing* comes to the fore but, in this case, it is more complicated than usual to reach the final result when the two periods differ by an almost exact ratio of 8:5. If a lightcurve at any period is close to symmetrical, then when doing a period search, it's often difficult to be sure if data from one session is being matched to the proper half of the lightcurve.

If a simple shift of 0.5 rotation phase of one of the halves would closely match the underlying half, then either the original or the half-period are possible and the period ratio will be such that dividing the two numbers has a fractional value of 0.0 or 0.5. It is not so simple if the fractional value is something else, such as a fractional value of 0.6 for the 8:5 period ratio. It may be helpful to note that one half of the lightcurve is trimodal and the other bimodal, though this will not always be the case.

We again observed the asteroid in 2017 December (Warner et al., 2018) and the data led to a period of 14.321 h, which was very close to the period of 14.298 h found by Ditteon et al. (2018). At that time, we re-examined the data from 2016 and found an alternate period of 14.329 h.

Re-analysis of the 2017 data for this work modified the period slightly to 14.320 h. It was obvious that a split-halves plot was not required to resolve an ambiguity; this was supported by the failed attempts to find a period close to 9 h that not even significant zero-point adjustments could overcome.





Moving to 2020, our observations from May 23 – June 8 led to a somewhat noisy dataset that contained only short runs (~3.5 h) that would cover about one-quarter of the 14.3-h period. The resulting period spectrum does not support the 9-hour solution, shows 14.3 h to be a secondary choice, and prefers 10.235 h.

Here, the periods of 10.235 h and 14.320 h are an almost exact 7:5 ratio or, as discussed above, one where the fractional value of dividing the two numbers is not 0.0 or 0.5 and so a simple shift of one half will not necessarily match the other half.

None of the previous datasets supported a period near 10.2 h. However, we recall the oft-cited phrase, “Absence of proof is not proof of absence,” meaning that, *based on the 2020 data alone*, one cannot completely ignore the 10.2-hour result and so it needed to be reported, even if it is unlikely when considering the other datasets. More data are needed to exclude a period of 10.2 h formally once and for all. In the meantime, for this work it was ruled out because of its very low probability.

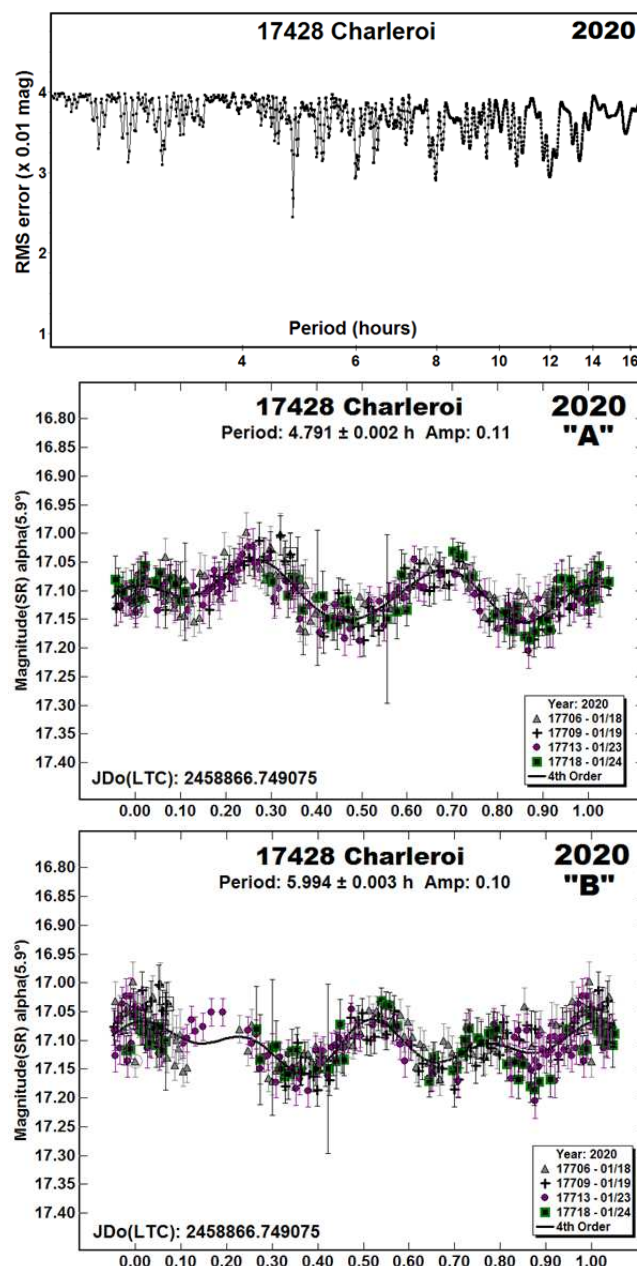
The low amplitudes in the 2016 and 2017 apparitions allowed for lightcurves that were monomodal or tri- and higher modal, not just bimodal (Harris et al., 2014). We adopted 14.317 h for the 2020 dataset since the minimums and maximums were about properly spaced for the bimodal lightcurve that was assumed because of the larger amplitude but despite the lack of full coverage.

Overall, we adopt the period of 14.320 h derived from the 2017 dataset, which had high-quality and, most important, provided an unambiguous solution that was closely supported by the other datasets. Even so, this asteroid needs more study to remove all reasonable doubts about its rotation period.

17428 Charleroi. Our results from earlier apparitions are the only ones listed in the LCDB. In Warner et al. (2017a) we reported a period of 5.990 h. In Warner et al. (2018) a similar period of 6.034 h was found. Our 2020 January observations *initially* led to a period of 5.335 h. That significant difference prompted a return to the earlier datasets to compare and contrast their results with those based on the latest dataset. The end result would be to bring the 2020 result into line with the others *and* introduce the possibility of *rotational aliasing*.

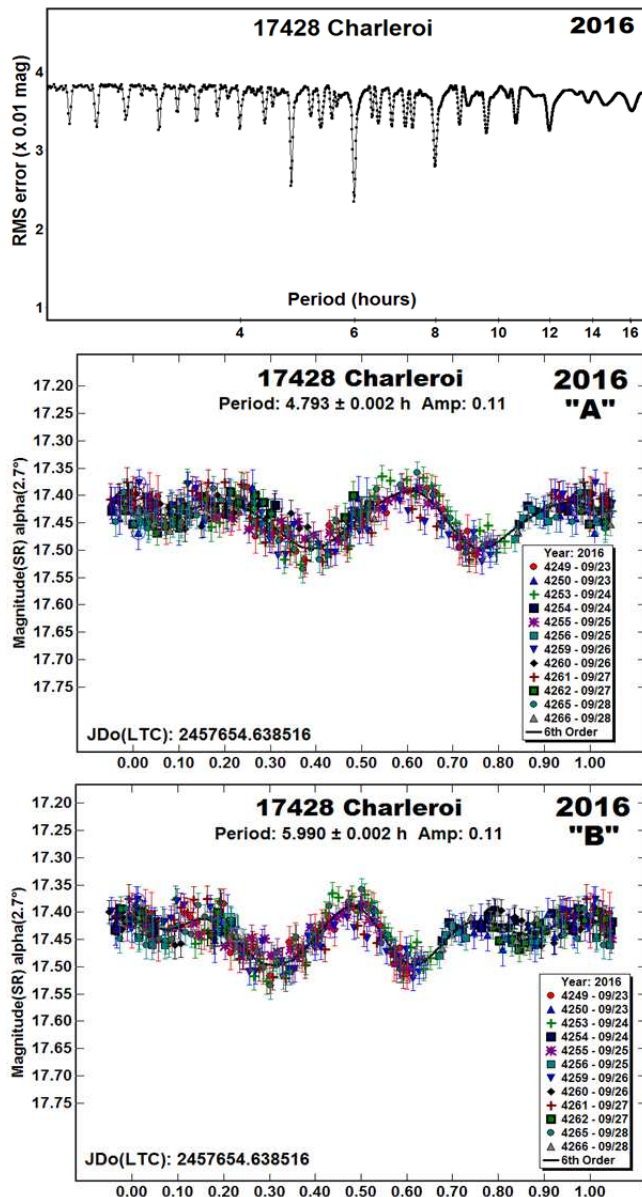
For the 2016 and 2017 datasets, the comparison star magnitudes were changed from another catalog to ATLAS (Tonry et al., 2018) SR (Sloan r') magnitudes so that we would have greater confidence in the night-to-night zero points.

The considerations of *rotation aliasing* for 1529 Oterma are the same here and will not be repeated in detail; only a brief summary for the analysis for each apparition will be given.



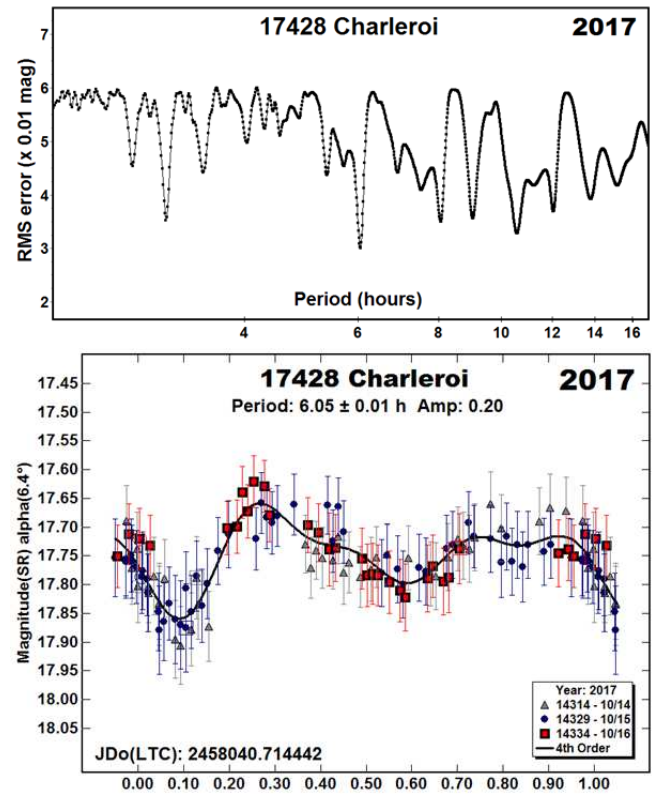
After going through re-analysis, the 2020 period spectrum no longer favored the 5.3-hour period; in fact, it's barely noticeable. Instead, a period of 5.994 h (2020 "B") was strongly favored. However, this produced an unusually-shaped lightcurve with gaps in coverage, raising the possibility of a *fit by exclusion*. A more "normal" lightcurve was found at a period of 4.791 h, or nearly an exact 5:4 ratio between the two periods.

The period spectrum from 2016 September dataset still favors 5.990 h (2016 "B") but a solution of 4.793 h (2016 "A") is a nearly-equal possibility. The lightcurve for the longer period has more complete coverage but the shape of the two is very similar: there is no obvious choice for which period is the correct solution.



The dataset from 2017 October was sparse, covered only three days, and was noisy. It would seem the least likely to resolve the ambiguities but a period near 6 h was the only possibility. A fit to 4.8 h was not worth recording, let alone considering.

A similar argument to the one used for 1529 Oterma applies here when choosing a period to adopt for this work, i.e., to adopt a period that is supported by all datasets despite the hard-to-resolve ambiguities that appear in some datasets. Our preference is the 5.990 h derived from the 2017 dataset since it is based on the densest dataset and provides complete coverage of the lightcurve.



It should go without saying that data from at least one other station at a much different longitude might have resolved any ambiguities. Such collaborations are encouraged, if possible.

Acknowledgements

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Number	Name	20yy/mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.
1529	Oterma	16/08/31-10/03	18.3, 14.8	55	-8	14.329 ^A 8.955	0.002 0.002	0.12 0.12	0.01 0.01
1529	Oterma	17/12/18-12/29	10.8, 8.3	127	4	14.320	0.002	0.13	0.01
1529	Oterma	20/05/23-06/08	7.8, 10.1	207	9	14.317 ^A 10.235	0.005 0.003	0.23 0.17	0.03 0.03
17428	Charleroi	16/09/23-09/28	*2.7, 2.5	4	9	5.990 ^A 4.793	0.002 0.002	0.11 0.11	0.01 0.01
17428	Charleroi	17/10/14-10/16	6.4, 6.0	47	5	6.05	0.01	0.20	0.02
17428	Charleroi	20/01/15-01/24	6.6, 4.5	186	-5	5.994 ^A 4.791	0.003 0.002	0.10 0.11	0.02 0.02

Table II. Observing circumstances. ^AAlternate period. The phase angle (α) is given at the start and end of each date range. L_{PAB} and B_{PAB} are the average phase angle bisector longitude and latitude (see Harris *et al.*, 1984).

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