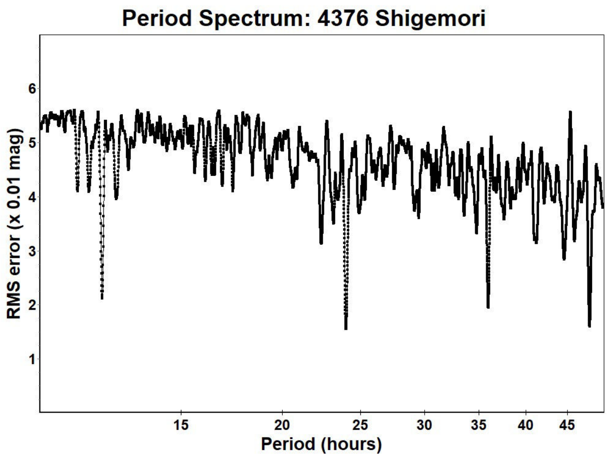

Acknowledgements

Minor Planet Circulars (MPCs) are published by the International Astronomical Union's Minor Planet Center. *https://www.minorplanetcenter.net/iau/ECS/MPCArchive/MPCArchive_TBL.html*

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A COMPREHENSIVE PHOTOMETRIC STUDY OF 603 TIMANDRA

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Based on 65 sessions 2022 Sept. 24 - Dec. 28, we find for 603 Timandra a synodic rotation period of 330.1 ± 0.5 hours and amplitude 0.80 ± 0.05 magnitudes. There is also low-level tumbling with a possible second period of 273 hours, PAR -2. The period, amplitude, and epoch of lightcurve maximum all agree with a recent posting on the DAMIT website. Data obtained on 2022 Oct. 15 show that (B-V) = 0.80 ± 0.04 and (V-R) = 0.51 ± 0.02. At mid-light, H = 12.18 ± 0.14 in the V band, G = 0.20 ± 0.17.

The first author of this paper (Pilcher, 2011) obtained twelve photometric sessions of 9 to 11 hours each on 603 Timandra 2010 Nov. 13 - Dec. 24. These data were measured with uncalibrated comparison stars, that is, instrumental magnitudes only. The zero points of the individual lightcurves were adjusted up to several ×0.1 magnitudes to provide a fit to a rotation period of 41.79 hours, amplitude 0.1 magnitudes. The uncalibrated data have been posted onto *www.ALCDEF.org* with sharing allowed. The reader is invited to download them and perform his own investigation.

Durech (2020) posted onto the DAMIT website a LI inversion model based entirely on sparse data from ATLAS between 2016/02 and 2018/10. The dense lightcurves obtained in 2010 by this author were not utilized to prepare the LI model presented in DAMIT. A sidereal period of 330.2 hours with rotational pole at celestial longitude 223º, celestial latitude 72º was found. The model shows a long equatorial axis about twice the length of the short equatorial axis. With a rotational pole nearly at a right angle to the orbital plane, a rotational amplitude near 0.7 magnitudes is expected.

The CCD images have been lost in the twelve years since they were made, but the original uncalibrated measurement data are preserved. First author Pilcher re-examined the original data obtained in the year 2010. When a lightcurve was drawn with the period forced to 330.2 hours, it was immediately apparent that there were many large gaps. Therefore, the half period of 165.1 hours was used to adjust the zero points of the individual sessions up to a few ×0.1 magnitudes until a good fit was obtained. With a range of periods between 160 hours and 170 hours thereafter adopted, small additional zero-point adjustments were made to minimize the rms residual at 164.9 hours.

For an amplitude of 0.8 magnitudes, a period with only one maximum and minimum per cycle cannot be fit to any model shape and is definitively ruled out. Therefore, we do not present the half period lightcurve. The period is twice as great. The final step was to adjust a lightcurve for best fit within a range of 325 to 335 hours. A period 330.5 ± 0.1 hours (formal error) and amplitude 0.8 ± 0.1 magnitudes is found and presented (Fig. 1). The real period error is likely to be larger.

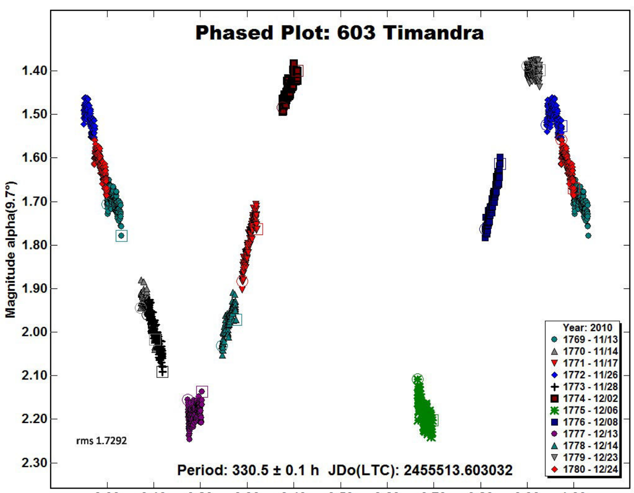

Fig. 1. The lightcurve of 603 Timandra phased to 330.5 hours drawn from year 2010 data.

A period spectrum between 100 hours and 400 hours shows deep minima only at 165 hours and at 330 hours (Fig. 2). Even with the data being uncalibrated, no period within this range except 330 hours can be allowed.

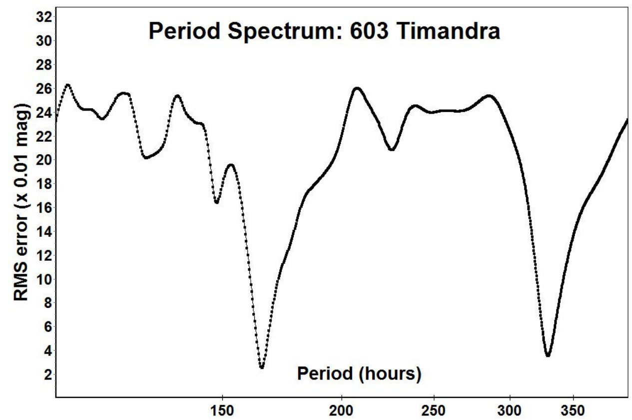

Fig. 2. The period spectrum of 603 Timandra for year 2010.

With another favorable opposition of 603 Timandra occurring in late 2022, first author Pilcher invited all the other authors of this paper to contribute photometric sessions. Observing circumstances and results are reported in table I. The full list of equipment of the several observers is provided below in table II. The target magnitudes in the R band for all sessions were calibrated with the r' magnitudes of solar colored stars in the CMC15 catalog, where R = r' - 0.22.

A total of 65 sessions, most of them less than 4 hours, were obtained by the several observers over the interval 2022 Sept. 24 to Dec. 28, including almost seven rotation cycles. Single period lightcurves were drawn with *MPO Canopus v. 10.7* software. Data from these sessions can be fit to a lightcurve with period 330.1 ± 0.1 hours (formal error), although we consider an error of ± 0.5 hours to be more realistic. The amplitude is 0.80 ± 0.05 magnitudes. Discordances in the plotted points for the several sessions suggest the presence of low-level tumbling. We present both a lightcurve phased to 330.1 hours (Fig. 3) and a raw lightcurve (Fig. 4), both including data from all sessions.

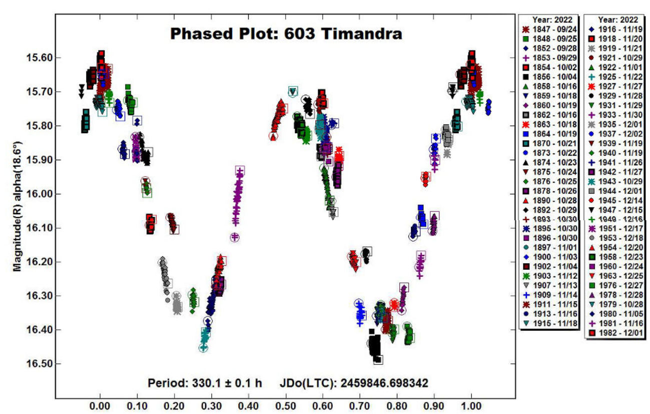

Fig. 3. The lightcurve of 603 Timandra phased to 330.1 hours drawn by single period software for year 2022 data.

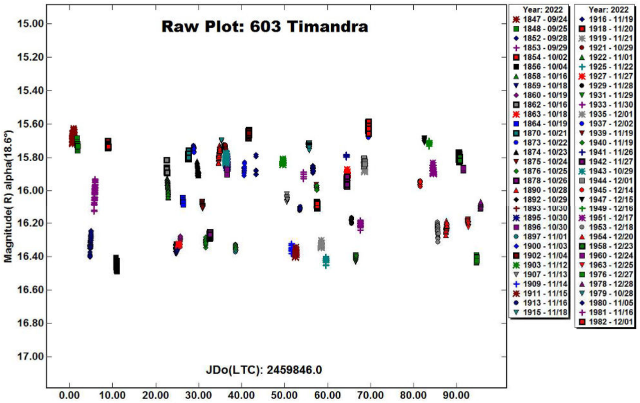

Fig. 4. The raw lightcurve of 603 Timandra for the interval 2022/09/24 to 2022/12/28.

It is instructive to explain how the 41.79-hour alias found in 2010 arose. The authors caution that similar mistakes may be present in other published data and warn all authors of lightcurves to look for evidence of the ambiguity explained in the next paragraph.

Let P1 = 41.79h, P2 = 330.1h, PE = Earth sidereal period 23.93h. Then (1/P1) - (1/P2) = 1/2PE within observational error. The calibrated data obtained in year 2022 immediately revealed the large amplitude and led to the correct period of 330.1 hours. If the data from the 2010 investigation had been calibrated instead of being arbitrarily adjusted, again the large amplitude would have been noted and the alias period rejected.

We consider this period to be highly reliable. The dense lightcurves from both the years 2010 and 2022 provide fits to a period very close to that obtained by LI modeling from sparse data in the years 2016-2018. The 330.5-hour lightcurve from year 2010 shows a maximum near JD2455513, shortly before zero epoch. Likewise, the 330.1-hour lightcurve from year 2022 shows a maximum near JD2459847, shortly after zero epoch. The DAMIT website has a provision that the LI model can be projected to any JD specified by the user. On both JD2455513 and JD2459847, the broad side of the model is toward the Earth and therefore the asteroid is at maximum light. The compatibility of rotation period, amplitude near 0.8 magnitudes predicted by the elongated shape model, and epoch of lightcurve maximum from three completely separate data sets improves the confidence in the shape and spin of the model, and in the validity of the 330.5-hour period obtained from the year 2010 dense but uncalibrated lightcurves.

Multiband photometry, acquired by P. Bacci and M. Maestripieri (104) on 2022 October 15, allowed us to determine the color indices (B-V) = 0.80 ± 0.04 and (V-R) = 0.51 ± 0.02 (Fig. 5), consistent with a medium albedo asteroid (Shevchenko and Lupishko, 1998).

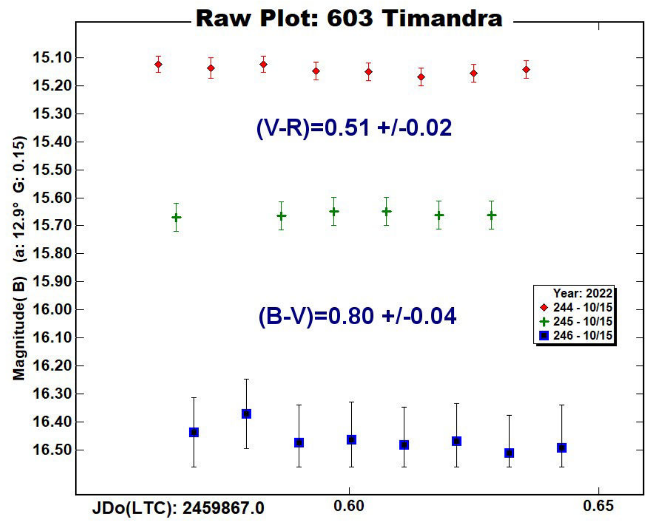

Fig. 5. Raw lightcurves of 603 Timandra in B, V, and R bands on 2022/10/15.

For H-G determination the R band magnitudes were converted to V band adding the color index (V-R). An H-G diagram was drawn for maximum, mean, and minimum light (Fig. 6). Considering the large amplitude of the lightcurve, for the H-G parameters were used separately the minimum and the maximum light magnitudes and evaluating the mean light solution (H = 12.18 ± 0.14 mag; G = 0.20 ± 0.17) which best represents the entire dataset.

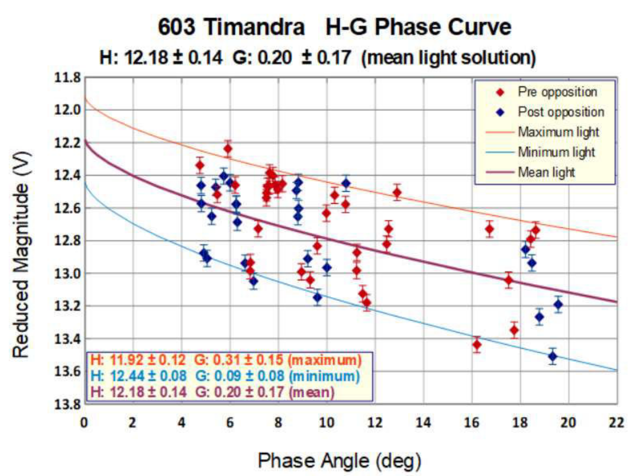

Fig. 6. V-band H-G diagram for 603 Timandra at maximum, mean, and minimum light.

The authors thank Petr Pravec for performing an independent analysis of our data, using software that includes the sum and difference of the primary and tumbling periods, and also the sum and difference of integer multiples of both periods. His analysis reads:

Number	Name	yyyy/mm/dd-yyyy/mm/dd	Phase	LPAB	BPAB	Period(h)	P.E	Amp	A.E.
603	Timandra	2010/11/13-2010/12/24	* 9.7, 13.4	67	11	330.5	0.5	0.80	0.10
603	Timandra	2022/09/24-2022/12/28	*18.6, 19.6	49	10	330.1	0.5	0.80	0.05

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date, where the * indicates that a minimum was reached between these dates. LPAB and BPAB are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).

Observatory (MPC code)	Telescope	CCD	Filter
Organ Mesa Observatory (G50)	0.35-m SCT f/10	SBIG STL-1001E	C
Astronomical Observatory of the University of Siena (K54)	0.30-m MCT f/5.6	SBIG STL-6303e(bin 2x2)	Rc
WBRO (K49)	0.235-m SCT f/10	SBIG ST8-XME	Rc
GAMP (104)	0.60-m NRT f/4	Apogee Alta	B,V,Rc
BSCR Observatory (K47)	0.41-m NRT f/3.2	DTA Discovery 1600	C
GiaGa Observatory (203)	0.36-m SCT f/5.8	MORAVIAN G2-3200	Rc
Tycho Observatory (M17)	0.20-m NRT f/4	SBIG ST10-XME	C
Beppe Forti Astronomical Observatory (K83)	0.40-m RCT f/8	SBIG STX 16803 (bin 3x3)	C
HOB Astronomical Observatory (L63)	0.20-m SCT f/6	ATIK 383L+	C
Iota Scorpii(K78)	0.40-m RCT f/8	SBIG STXL-6303e (bin 2x2)	Rc

Table II. Observing Instrumentations. MCT: Maksutov-Cassegrain, NRT: Newtonian Reflector, RCT: Ritchey-Chretien, SCT: Schmidt-Cassegrain.

While the main period of the tumbler is well established (330.5 h with a realistic error about 1h), its second period is not well determined. One of a few possible periods is 273.5 h, but it is possible that it is actually a linear combination of the real frequencies of the tumbler rather than the real second period. A part of the problem is that the data cannot be fitted to very high orders, so the fit is not perfect. I rate this one as PAR = -2. The primary period lightcurve is shown in Fig. 7.

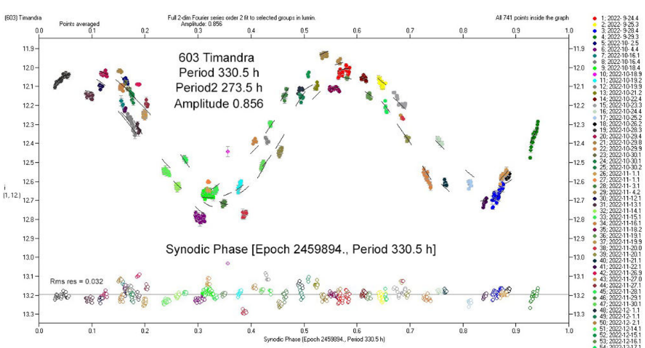

Fig. 7. Lightcurve of 603 Timandra for the year 2022 phased to 330.5 hours and drawn with multiple period software.

Acknowledgments

The authors thank Petr Pravec for his independent analysis of our data.

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