

References

- DSFTA (2024). Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente – Astronomical Observatory.
<https://www.dsfta.unisi.it/en/research/labs/astronomical-observatory>
- Harris, A.W.; Young, J.W.; Scaltriti, F.; Zappala, V. (1984). “Lightcurves and phase relations of the asteroids 82 Alkeme and 444 Gytis.” *Icarus* **57**, 251-258.
- JPL (2024). Small-Body Database Browser.
<http://ssd.jpl.nasa.gov/sbdb.cgi#top>
- Mainzer, A.K.; Bauer, J.M.; Cutri, R.M.; Grav, T.; Kramer, E.A.; Masiero, J.R.; Sonnett, S.; Wright, E.L. (2019). “NEOWISE Diameters and Albedos V2.0.” *NASA Planetary Data System*,
<https://doi.org/10.26033/18S3-2Z54>.
- Warner, B.D.; Harris, A.W.; Pravec, P. (2009). “The Asteroid Lightcurve Database.” *Icarus* **202**, 134-146. Updated 2023 Oct.
<http://www.minorplanet.info/lightcurvedatabase.html>
- Warner, B.D. (2018). MPO Software, MPO Canopus v10.7.7.0. Bdw Publishing. <http://minorplanetobserver.com>

LIGHTCURVE AND ROTATION PERIOD ANALYSIS OF (1685) TORO

Jiarui Xiong

Xingyuan Observatory
College of Oceanic and Atmospheric Science,
Ocean University of China
Songling Rd. 238, Qingdao, Shandong, CHINA
xiongjiarui@stu.ouc.edu.cn

Yue Lu

Xingyuan Observatory
Xingyuan College, Ocean University of China
Songling Rd. 238, Qingdao, Shandong, CHINA

Chenyang Guo

Xingyuan Observatory
Third Institute of Oceanography, Ministry of Natural Resources,
PRC
Daxue Rd. 178, Siming District, Xiamen, Fujian, CHINA

(Received: 2024 August 8)

Ten sets of photometric observations of the near-Earth asteroid 1685 Toro were obtained between 2024 January 26 and February 26. Using *Tycho Tracker* software, we plotted the lightcurve of 1685 Toro and measured its rotation period to be 10.1774 ± 0.012 h with a lightcurve amplitude of 0.51 ± 0.05 mag.

1685 Toro is a near-Earth Apollo asteroid that was discovered in 1948 July by C.A. Wirtanen at Mount Hamilton. A total of 1875 images were taken on ten nights between 2024 January 26 to February 26. We used an $f/4$ 0.2-m reflector and ASI6200MM CCD camera operating at -20 degrees C. Given Toro's large sky motion, exposure times were between 60 and 120 seconds. All of the frames were taken under L band (unfiltered).

Tycho Tracker was used for data analysis and measurement. Bias, flat, and dark frames were applied and the images aligned prior to measuring. The V magnitudes from APASS were used for the comparison stars. According to the asteroid lightcurve database (LCDB; Warner et al., 2009), the mean absolute magnitude is $H = 14.48 \pm 0.13$ if assuming a phase slope parameter $G = 0.24 \pm 0.11$. We used these values in our analysis. A fourth-order Fourier lightcurve was fit to $P = 10.1774 \pm 0.012$ h for a light-time corrected zero-point of JD = 2460336.0.

The rotation period of 1685 Toro is known (Durech et al., 2022) to be affected by YORP (Rubincam, 2000) based on data from 1972, 1988 (Hoffmann and Geyer, 1990), 2007 (Higgins, 2008, 2011) and (Higgins et al. 2008), 2013 (Warner, 2013). In the YORP model, a free parameter $\nu \equiv \frac{d\omega}{dt}$ is used to express rotational acceleration. Assuming a linear model, the period can be calculated as:

$$P(t) = \frac{2\pi P_0}{\nu P_0(t - T_0) + 2\pi}$$

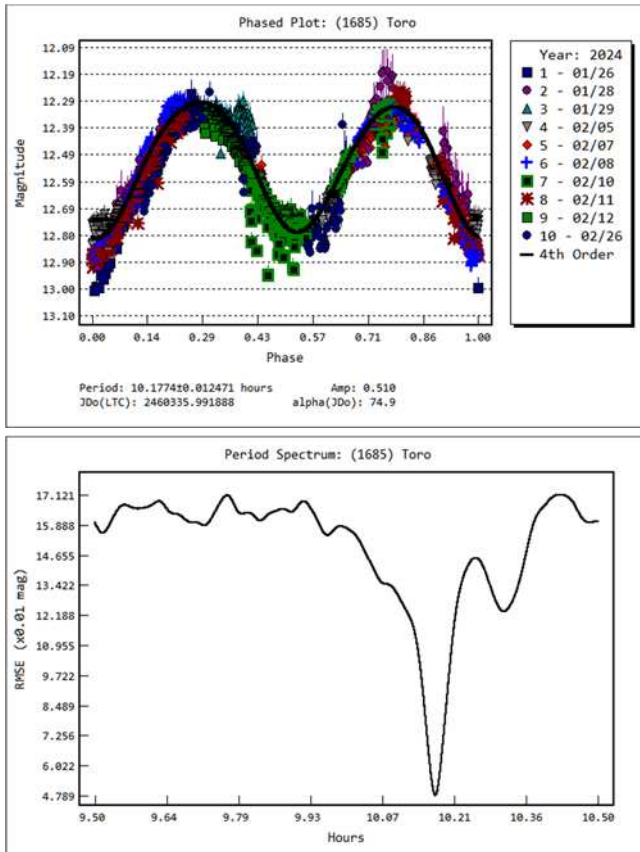
Where:

- t: the time of observation (JD).
 T_0 : the epoch from which the model is propagated.
 P_0 : the rotation period of Toro from which the model is propagated.
 $P(t)$: the rotation period of (1685) Toro at a certain time, t.

Tian et al. (2022) suggest YORP acceleration $\nu = (3.2 \pm 0.3) \times 10^{-9}$ rad·day⁻² (1 σ error). Using $T_0 = 2441507.0$, $P = 10.197826 \pm 0.000002$ hours (Tian et al, 2022). Toro's rotation period at the time of observation is $P = 10.197675 \pm 0.000165$ hours. Meanwhile, this work's result is $P = 10.1774 \pm 0.012$ hours. There is evidence that the rotation rate is accelerating; however, more accurate data are required to analyze if any other effects changed its rotation period.

ID	JD	Period in hours	Author
1	2441507.0	10.197826 ± 0.000002	Đurech et al., 2002
2	2447379.0	10.1995 ± 0.0018	Hoffmann & Geyer, 1990
3	2454244.0	10.1995 ± 0.0004	Higgins, 2008
4	2454513.9	10.1862 ± 0.0006	Higgins et al. 2008
5	2455324.8	10.199 ± 0.003	Higgins, 2011
6	2456152.8	10.188 ± 0.002	Warner, 2013
7	2260336.0 (This work)	10.1774 ± 0.012	Xiong et al.

Table I. (1685) Toro's rotation period in hours observed from 1972 to present. Note that the uncertainties in IDs 3-6 lack detailed confidence degrees, suggesting they should be given less weight.



Acknowledgements

This work is supported by Xingyuan College of Ocean University of China. This work is possible in part based on data from AAVSO Photometric All-Sky Survey (APASS) and software *Tycho* v11.0.1 developed by Daniel Parrott. We want to express our special thanks to Dr. Ye Yuan in Pulper Mount Observatory and Astronomical Associations of the Ocean University of China. Thanks to Deng Linxi, Yan Yirou, Jiang Bicong, and Gao Shijie's help checking this article. Thanks Shao Yushuang provided checking in data analysis.

References

- Đurech, J.; Vokrouhlický, D.; Pravec, P. and 28 colleagues (2022). "Rotation acceleration of asteroids (10115) 1992 SK, (1685) Toro, and (1620) Geographos due to the YORP effect." *Astron. Astrophys.* **657**, A5.
- Higgins, D. (2008). "Asteroid Lightcurve Analysis at Hunters Hill Observatory and Collaborating Stations: April 2007 - June 2007." *Minor Planet Bull.* **35**, 30-32.
- Higgins, D.; Pravec, P.; Kusnirak, P.; Hornoch, K.; Brinsfield, J.W.; Allen, B.; Warner, B.D. (2008). "Asteroid Lightcurve Analysis at Hunters Hill Observatory and Collaborating Stations: November 2007 - March 2008." *Minor Planet Bull.* **35**, 123-126.
- Higgins, D. (2011). "Period Determination of Asteroid Targets Observed at Hunters Hill Observatory: May 2009 - September 2010." *Minor Planet Bull.* **38**, 41-46.
- Hoffmann, M.; Geyer, E.H. (1990). "Photometric Observations of Three Near-Earth Asteroids." *ACTA Astronomica* **40**, 389-396.
- Rubincam, D.P. (2000). "Radiative Spin-up and Spin-down of Small Asteroids." *Icarus* **148**, 2-11.
- Tian, J.; Zhao, H.B. Li, B. (2022). "Shape Model and Rotation Acceleration of (1685) Toro and (85989) 1999 JD6 from Optical Observations." *RAA* **22**, 17pp
- Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2023 Oct. <http://www.minorplanet.info/lightcurvedatabase.html>
- Warner, B.D. (2013). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2012 June - September." *Minor Planet Bull.* **40**, 26-29.