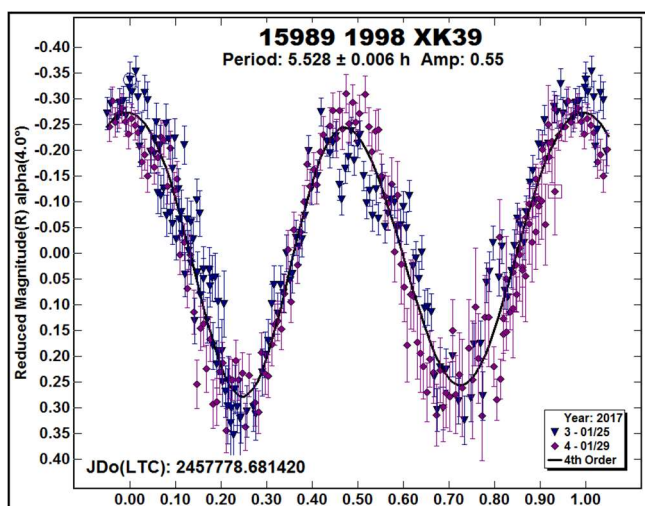




Acknowledgements

The authors would like to acknowledge the IAU ROAD offices, including NA-ROAD, WA-ROAD, and SA-ROAD; and Geneva Lake Astrophysics and STEAM (GLAS) Education, in Lake Geneva, Wisconsin. We would like to specially thank Matt Nowinski, Kate Meredith, Amanda Pagul, Adam McCulloch, and Katya Gozman. Our deepest appreciation is also extended to the McQuown Trust for financial support and access to the Stone Edge Observatory, Sonoma, CA.

References

- Carvano, J.M.; Hasselmann, P.H.; Lazzaro, D.; Mothe-Diniz, T. (2010). "SDSS-based taxonomic classification and orbital distribution of main belt asteroids." *Astronomy and Astrophysics* **510**, 1-12.
- Harris, A.W.; Young, J.W.; Scaltriti, F.; Zappala, V. (1984). "Lightcurves and phase relations of the asteroids 82 Alkmene and 444 Gyptis." *Icarus* **57**, 251-258.
- Masiero, J.R.; Mainzer, A.K.; Grav, T.; Bauer, J.M.; Cutri, R.M.; Dailey, J.; Eisenhardt, P.R.M.; McMillan, R.S.; Spahr, T.B.; Skrutskie, M.F.; Tholen, D.; Walker, R.G.; Wright, E.L.; DeBaun, E.; Elsbury, D.; Gautier IV, T.; Gomillion, S.; Wilkins, A. (2011). "Main Belt Asteroids with WISE/NEOWISE. I. Preliminary Albedos and Diameters." *The Astrophysical Journal* **741**, 1-68.
- Nesvorný, D. (2015) "Nesvorný HCM Asteroid Families V3.0." *EAR-A-VARGDET-5-NESVORNYFAM-V3.0. NASA Planetary Data System*.
- Oszkiewicz, D.; Kankiewicz, P.; Włodarczyk, I.; Kryszczyńska, A. (2015). "Differentiation signatures in the Flora region." *Astronomy and Astrophysics* **584**, 1-14.
- Roig, F.; Folonier, H.; Beaugé, C.; Ribeiro, A.O. (2011). "Dynamical origin of V-type asteroids outside the Vesta family." *Workshop Series of the Asociacion Argentina de Astronomia* **3**, 307-317.
- Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2016 Sep. <http://www.minorplanet.info/lightcurvedatabase.html>
- Warner, B.D. (2019). *MPO Canopus* Software, version 10.8.1.1. BDW Publishing. <http://www.bdwpublishing.com>

OBSERVATIONS OF 148 GALLIA

Neil B. Thomas
U.S. Air Force Academy
PO Box 978, Palmer Lake, CO 80133
neil.thomas@afacademy.af.edu

Patrick R. Lopez
U.S. Air Force Academy
Colorado Springs, CO, USA

(Received: 2021 May 3, Revised: 2021 August 5)

Photometric observations of 148 Gallia are reported as the asteroid approached opposition. We conducted 17 observing sessions between 2021 Feb 27 to 2021 Apr 9. This paper provides the full phase-folded lightcurve and reduced magnitude of this asteroid which has a spin period of slightly more than 20 h.

148 Gallia is a member of the MB-O group/family. It was discovered in 1875 by Prosper Henry. Its diameter is 98 km, and it has a relatively high inclination of 25.2°. We could not readily find an existing dense lightcurve covering the full phase of its rotation, although Warner (2007) covered it well enough to characterize its nature. No additional photometry was found in the Lightcurve Database (Warner et al., 2009). Considering its brightness, it is likely not heavily studied due to its period of slightly more than 20 h. This implies less than half of a phase being available each night and only about a 20% phase shift per day due to the earth's 24-hour day. Hence, a continuous campaign would require approximately five consecutive nights for full coverage.

The Lookout Observatory (LO) is primarily dedicated to the characterization of exoplanet transit lightcurves. As such, it typically attains a photometric precision of 1-2 thousandths of a magnitude (mmag) for well exposed targets. The telescope is an 11-inch Celestron modified to f/1.9 with a HyperStar, providing a field of view of 114 × 86 arcmin (or 2.7 degrees²) when coupled to an ASI 1600 CMOS camera. All photometry was unfiltered with exposures of 36 seconds.

We recently modified our exoplanet software to detect and track asteroids with the goal of obtaining lightcurves serendipitously during the ongoing exoplanet survey. Stars are subtracted from our reference image using Gaia catalog locations and magnitudes (Gaia Collab., 2018). Remaining objects are automatically compared to DSS imagery to eliminate galaxies. Remaining objects are examined over time to determine drift rate. If a consistent tracking solution is found, then this information is recorded and used to move the photometric aperture during the rest of the processing. We developed a test campaign targeting 148 Gallia since it was well-positioned and approaching opposition.

Gallia was the primary target from 2021 Feb 27 to 2021 Apr 9 (41-day span). This allowed for analysis of this moderate-period asteroid (20.66 h), to include a complete phase folded lightcurve. Most portions of the phase were observed on two or more occasions. All data is light time corrected (LTC) and approximately reduced to H. This is approximate since our software relies on Gaia DR2 for absolute magnitude calibration to the green (G) band. G-band is comparable to visual (V-band) but not precisely the same. After phase folding the 6,184 observations to our derived period, we bin data to simulate exposures of approximately two minutes for clarity and to reduce white noise. Six sessions required no

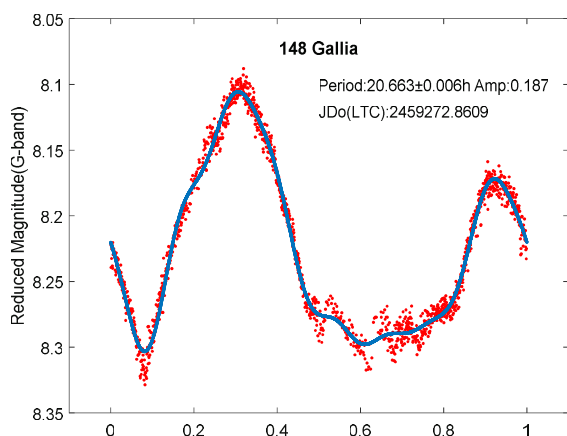
Number	Name	yyyy mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
148	Gallia	2021 02/27-04/09	14.0, 8.7	199	24	20.661	0.006	0.19	0.01	MB-O

Table I. Observing circumstances and results. The phase angle is given for the first and last date. 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).

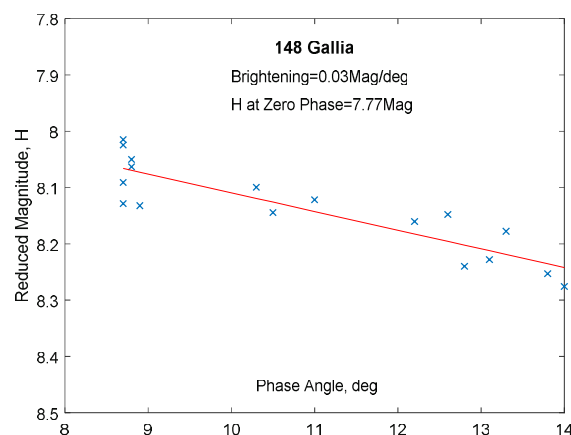
magnitude adjustments in creating the phase curve while the other 11 were manually adjusted with offsets on the order of 0.03 magnitude or less.

A summary of the results is detailed in the table below along with the subsequent figures. Column 3 provides the date of the observation; column 4 provides the phase. Columns 5 and 6 provide the longitude and latitude of the Phase Angle Bisector (PAM), respectively. Columns 7 through 10 provide our derived periods and amplitudes, as well as their errors. The group or family is given in column 11.

The synodic period based on only our observations is 20.661 ± 0.006 h and agrees with Warner's of 20.666 ± 0.002 h (Warner, 2007). The amplitude agrees as well, with our result being 0.19 ± 0.01 mag and Warner's being 0.21 ± 0.02 mag. The features of the curve itself, however, are significantly different. This is not surprising because even though phase angles at the times of observation were similar, the PAM coordinates differed greatly. We observe a sharp drop in the first minimum and a flat bottom in the second. Additionally, the two minima are not separated by half of the period. The RMS between our 7th order trigonometric fit and our data is 7.5 mmag. This is not as good as our stellar photometry, but we expect degraded results with a moving target.



The reduced magnitude as the asteroid approached opposition from an initial phase of 14 degrees was then investigated. The expected linear brightening with reduced phase is observed. The minimum phase angle at opposition is slightly less than 9 degrees due to Gallia's large inclination. Thus, no opposition effect was noted. When this brightening is extrapolated to zero phase, we arrive at $H=7.7$, which agrees nicely with the accepted value of 7.72 (Warner, 2007).



Acknowledgements

In addition to the support of the Astronautical Engineering Department at the US Air Force Academy (specifically Col Luke Sauter for the powerful gift of time), the authors would like to thank the LO construction team, Savannah Jane and P.P. This work presents results from the European Space Agency (ESA) space mission Gaia. Gaia data are being processed by the Gaia Data Processing and Analysis Consortium (DPAC). Funding for the DPAC is provided by national institutions, in particular the institutions participating in the Gaia MultiLateral Agreement (MLA). The Gaia mission website is <https://www.cosmos.esa.int/gaia>. The Gaia archive website is <https://archives.esac.esa.int/gaia>.

References

- Gaia Collaboration (2018). "Gaia Data Release 2. Summary of the contents and survey properties" *AA*, **616A**.
- Harris, A.W.; Young, J.W.; Scaltriti, F.; Zappala, V. (1984). "Lightcurves and phase relations of the asteroids 82 Alkmene and 444 Gyptis." *Icarus* **57**, 251-258.
- Warner, B.D. (2007). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory - March - May 2007." *Minor Planet Bulletin* **34**, 104-107.
- Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2020 Oct. <http://www.minorplanet.info/lightcurvedatabase.html>