

# THE ROTATION PERIOD OF 699 HELA CORRECTED

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For 699 Hela we present an unambiguous and reliable synodic rotation period of 3.396 hours, correcting an earlier published aliased value. The problem of aliasing of lightcurve periods is explained, with means of guarding against their appearance suggested.

Often in the process of obtaining lightcurves of minor planets short intervals of observation are separated by much longer intervals in which no data could be obtained due to weather or unavailability of telescope time. In these cases it may not be possible to determine the exact number of rotational cycles between the widely separated data sets. Several different periods may satisfy the observational data almost equally well. This problem can arise even for lightcurves on successive nights, and is especially severe when the period has a commensurability with the Earth's 24 hour period. The incorrect periods appearing among these are called aliases.

In 1982 E. Bowell, Lowell Observatory, informed one of the authors (FP) that planet 699 Hela had a short period near 3.6 hours and large amplitude around 0.7 magnitudes. This seemed ideal for visual photometry, and in addition to one photoelectric run by R. P. Binzel at McDonald Observatory and two by M. Watt at Lowell Observatory, FP made a large number of visual lightcurves so that an unusually large interval of 71 days was covered by the data. On this basis Pilcher (1983) published a period of  $3.6557 \pm 0.0002$  hours. In the years following publication Pilcher began to doubt the reliability of this period, believing he may have miscounted one-half cycle each day. The opportunity to check this suspicion came at the very favorable apparition of 699 Hela in September, 1999, when additional photometric lightcurves were made by Brian D. Warner (BDW) and Vittorio Goretti (VG).

Two unfiltered CCD observing runs were made by BDW on UT 1999 September 14 and 17, with the 25-cm telescope at the Palmer Divide Observatory. The amplitude was only 0.17 magnitude at the 1999 aspect. Fourier analysis yielded a period of  $3.3987 \pm 0.002$  hours, demonstrating that the original published period was indeed an alias. Figure 1 presents the composite lightcurve of these two nights.

One of us (VG) made two additional lightcurves measurements with a 25 cm Schmidt-Cassegrain + CCD with a V filter on UT 1999 September 21 and 29. These are shown, light time corrected, in Figures 2 and 3, respectively.

In Table I below the original data of the 1982 paper are presented again, and to these the corrections in the original data analysis are added. The observer code, observed extremum, and its light time corrected observed 1982 ET, are presented in respective columns 1, 2, and 3. Columns 4 and 5 state respectively the rotation cycle number for assumed 3.6557 hour period, and the O-C (observed minus computed) residual of the observed time. By adding 0.5 rotation cycles for each day after the first observation June 13.355, rotation cycle numbers for a 3.3966 hour period are obtained and presented in column 6. Column 7 then presents the O-C for this assumption. The residuals for this assumption are somewhat smaller than for the alias period. The least squares data reduction is best satisfied by a synodic period of  $3.3966 \pm 0.0002$  hours.

Table II below provides analogous data for the 4 nights in September 1999 by BDW and VG. Observer code, observed extremum, and its light time corrected observed 1999 ET, are presented in respective columns 1, 2, and 3. The longitude span between the two observers shows that a 3.6557 hour period is untenable; the combined data can be satisfied only with a synodic period whose least squares value is  $3.3957 \pm 0.0006$  hours.

The 1982 data set is entirely by observers in central North America, for which not even the 71 day time interval of observation could unambiguously distinguish the number of unobserved cycles from

Table I. 1982 lightcurve extrema of 699 Hela, light time corrected

| 1982 ET  |          |            |          |       |        |        |  |
|----------|----------|------------|----------|-------|--------|--------|--|
| Observer | light    | Assumed    | Assumed  |       |        |        |  |
| Code     | time     | Rotation   | Rotation | O-C   | Cycle  | O-C    |  |
|          | Extremum | corrected  | Cycle    |       |        |        |  |
| B        | Max      | Jun 13.355 | 0.00     | .000d | 0.00   | +.002d |  |
| B        | min      | 13.384     | 0.25     | -.009 | 0.25   | -.004  |  |
| W        | Max      | 19.299     | 39.00    | +.003 | 42.00  | +.002  |  |
| P        | min      | Jul 13.173 | 195.75   | +.001 | 210.75 | -.006  |  |
| P        | Max      | 13.211     | 196.00   | +.001 | 211.00 | -.004  |  |
| P        | min      | 13.250     | 196.25   | +.002 | 211.25 | .000   |  |
| P        | Max      | 13.288     | 196.50   | +.002 | 211.50 | +.002  |  |
| P        | Max      | 16.256     | 216.00   | .000  | 232.50 | -.002  |  |
| P        | min      | 17.283     | 222.75   | -.001 | 239.75 | -.001  |  |
| P        | Max      | 17.319     | 223.00   | -.003 | 234.00 | .000   |  |
| P        | min      | 17.361     | 223.25   | .000  | 234.25 | +.007  |  |
| P        | min      | 18.131     | 228.25   | +.009 | 245.75 | -.002  |  |
| P        | Max      | 18.166     | 228.50   | +.006 | 246.00 | -.002  |  |
| P        | min      | 18.204     | 228.75   | +.006 | 246.25 | .000   |  |
| W        | Max      | 19.225     | 235.50   | -.001 | 253.50 | -.005  |  |
| W        | min      | 19.261     | 235.75   | -.004 | 253.75 | -.004  |  |
| W        | Max      | 19.297     | 236.00   | -.006 | 254.00 | -.003  |  |
| W        | min      | 19.337     | 236.25   | -.004 | 254.25 | +.001  |  |
| W        | Max      | 19.370     | 236.50   | -.009 | 254.50 | -.001  |  |
| W        | min      | 19.407     | 236.75   | -.010 | 254.75 | +.001  |  |
| W        | Max      | 19.442     | 237.00   | -.013 | 255.00 | .000   |  |
| P        | Max      | 24.187     | 268.00   | +.010 | 285.00 | +.004  |  |
| P        | min      | 24.222     | 268.25   | +.007 | 228.75 | +.004  |  |
| P        | Max      | 24.263     | 268.50   | +.010 | 289.00 | +.005  |  |
| P        | Max      | 25.248     | 275.00   | +.005 | 296.00 | .000   |  |
| P        | min      | 25.285     | 275.25   | +.004 | 296.25 | +.001  |  |
| P        | Max      | 25.325     | 275.50   | +.005 | 296.50 | +.006  |  |
| P        | Max      | Aug 21.129 | 451.50   | +.002 | 486.00 | -.005  |  |
| P        | min      | 21.167     | 451.75   | +.001 | 486.25 | -.003  |  |
| P        | Max      | 21.204     | 452.00   | .000  | 486.50 | -.001  |  |
| P        | min      | 21.243     | 452.25   | +.001 | 486.75 | +.003  |  |
| P        | Max      | 21.281     | 452.50   | +.001 | 487.00 | +.005  |  |
| P        | Max      | 24.171     | 471.50   | -.003 | 507.50 | -.006  |  |
| P        | min      | 24.206     | 471.75   | -.006 | 507.75 | -.006  |  |
| P        | Max      | 24.246     | 472.00   | -.004 | 508.00 | -.002  |  |
| P        | min      | 24.285     | 472.25   | -.003 | 508.25 | +.002  |  |

Observer code: B: R. P. Binzel, photoelectric photometry at McDonald Observatory. P: F. Pilcher, visual photometry with the 35 cm telescope at the Walter H. Balcke Observatory, Illinois College, Jacksonville, Illinois. W: M. Watt, photoelectric photometry at Lowell Observatory.

one night to the next and allowed the one half cycle per day error to arise. By contrast the 1999 data set involved observers in North America and Europe. With observations at widely varying fractions of a day, the alias period was definitively ruled out, and only a period near 3.396 hours is allowed.

The  $3.3966 \pm 0.0002$  hour period was found at a large amplitude, near equatorial aspect. The  $3.3957 \pm 0.0006$  hour period was found at a small amplitude, near polar aspect. These data show that 699 Hela has a large obliquity. At near equatorial aspect for a large obliquity object the synodic and sidereal periods are nearly the same, whereas at near polar aspect they have a greater difference. We therefore suggest that the 3.3966 hour period is closer to the sidereal, with the caution that additional lightcurves are required to verify this suggestion.

Every method of lightcurve analysis, including Fourier series analysis of every point in a precision photoelectric lightcurve, introduces alias periods when long intervals exist in which no observations are available. To eliminate these, the authors request a cooperative program by observers in widely spaced longitudes around the Earth. Most alias periods will be eliminated immediately by such a procedure, for which the data for 699 Hela in 1999 are an outstanding example. We recommend that target objects for this cooperative program include those published quarterly in MPB in the ASTEROID PHOTOMETRY OPPORTUNITIES by Petr Pravec and Alan W. Harris, and large lightcurve objects found in the MAP program and announced by e-mail by Lawrence Garrett.

#### References

Pilcher, F., (1983). *MPB* 10, 18-20.

Table II. 1999 lightcurve extrema of 699 Hela, light time corrected

| Observer | Extremum | 1999 ET<br>light<br>time | Assumed P=3.3957h<br>Rotation<br>Cycle | O-C    |
|----------|----------|--------------------------|----------------------------------------|--------|
| Code     |          | corrected                |                                        |        |
| W        | Max      | Sep 14.146               | 0.00                                   | -.003d |
| W        | min      | 14.182                   | 0.25                                   | -.002  |
| W        | Max      | 14.222                   | 0.50                                   | +.002  |
| W        | min      | 14.258                   | 0.75                                   | +.003  |
| W        | Max      | 14.288                   | 1.00                                   | -.002  |
| W        | min      | 14.322                   | 1.25                                   | -.004  |
| W        | Max      | 17.121                   | 21.00                                  | +.001  |
| W        | min      | 17.159                   | 21.25                                  | +.003  |
| W        | Max      | 17.189                   | 21.50                                  | -.002  |
| G        | Max      | 21.795                   | 54.00                                  | +.006  |
| G        | min      | 21.817                   | 54.25                                  | -.008  |
| G        | Max      | 21.861                   | 54.50                                  | +.001  |
| G        | min      | 21.899                   | 54.75                                  | +.004  |
| G        | Max      | 29.782                   | 110.50                                 | -.001  |
| G        | min      | 29.819                   | 110.75                                 | .000   |
| G        | Max      | 29.852                   | 111.00                                 | -.002  |
| G        | min      | 29.890                   | 111.25                                 | -.001  |

Observer code: W: B. D. Warner, CCD photometry with a 25 cm telescope at Colorado Springs, Colorado, USA. G: V. Goretti, CCD photometry with a 25 cm f/4 Schmidt Cassegrain at Pianoro, Italy.

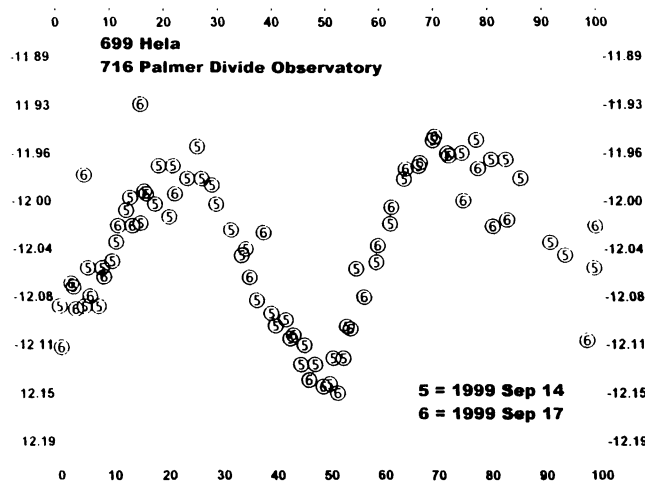


Figure 1.

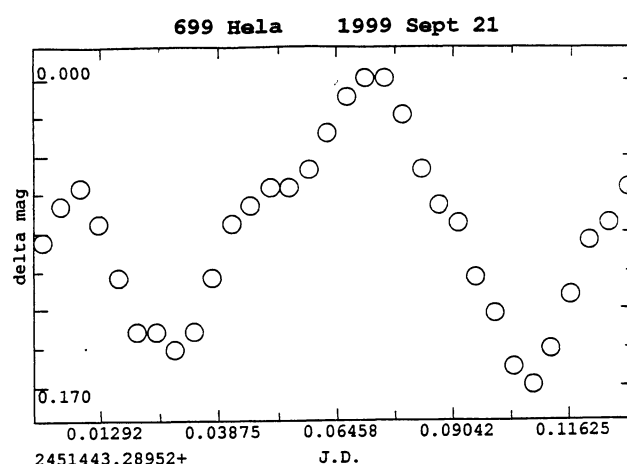


Figure 2.

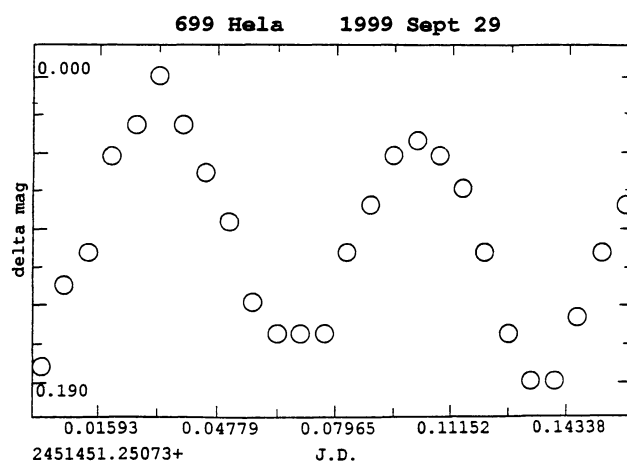


Figure 3.