(31345) 1998 PG: A BINARY NEAR-EARTH ASTEROID?

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Photometric observations of the near-Earth asteroid (31345) 1998 PG by Pravec et al. (2000) found a rotation period of 2.51620 h. Also found was a secondary period of 7.0035 h, or the double-period of 14.007 h, possibly indicating an additional body in the system. An extended campaign by the authors in 2018 lead to a similar primary period of 2.5168 h. However, instead of a 7-hour secondary period, one of about 16 hours was found with the lightcurve showing apparent mutual events (occultations and/or eclipses). The data sets from 1998 and 2018 could not be fit to a secondary period near the one found at the opposing apparition. The conclusion is that the asteroid is very likely binary, but – other than the primary rotation period – the system's parameters are ill-defined and only future observations will sufficiently refine them.

(31345) 1998 PG is a near-Earth asteroid (NEA) with an estimated diameter of 0.9 km (LCDB; Warner et al., 2009). The first reported rotation period came from Kiss et al. (1999), who found a period of 2.5 hours based on a sparse data set. Pravec et al. (2000) performed an extensive campaign in 1998, shortly after the asteroid's discovery.

Analysis of their data found a primary rotation period of P_1 = 2.51620 ± 0.00003 h and lightcurve amplitude of 0.11 mag. They also found a secondary period with a period of P_2 = 7.0035 ± 0.0007 h (A = 0.09 mag) that produced a monomodal lightcurve. This was interpreted as indicating a second body in the system. Allowing for the possibility that P_2 was actually the half-period and that the putative satellite's rotation period was tidally locked to its orbital period, they suggested that the double-period was the correct solution, i.e., P_2 = 14.007 ± 0.0014 h. A check for a third period found a very weak solution that was not considered reliable since its amplitude rivaled the scatter in the data.

In 2018, a new campaign involving observers in North America, Europe, and Australia lead to essentially the same results for P_1 but not for P_2. Table I shows the list of observers and the instrument used by each one.

OBS	Telescope	Camera
Warner (BW)	0.50m R-C 0.35m SCT	FLI PL-1001E FLI ML-1001E
Aznar (AA)	1.50m N-C	Andor iKon-L 936
Benishek (VB)	0.35m SCT	SBIG ST-8/10XME
Oey (JO)	0.61m CDK	Apogee U16M
Pray (DP)	0.50m NWT	ST-10XME

Table I. The instrumentation used by the observers. SCT: Schmidt-Cassegrain; R-C: Ritchey-Chretien; N-C: Nasmyth-Cassegrain; CDK: Corrected Dall-Kirkham; NWT: Newtonian reflector.

All observations were unfiltered with exposures based on the telescope used and asteroid magnitude. Each observer measured his own images, which were flat-field and dark frame corrected, using *MPO Canopus*. The Comp Star Selector utility was used to find up to five near solar-color stars for ensemble differential photometry. Catalog magnitudes were taken from the APASS (Henden et al., 2009), CMC-15 (Munos, 2017), or MPOSC3 catalogs.

All observers used V magnitudes, except Pray, who used R. The V magnitudes are native only to the APASS catalog. The R magnitudes are not native to any of the three. For CMC-15, conversion formulae by Jester (2005) were used to get V magnitudes. For the MPOSC3, which is a hybrid based on the 2MASS catalog, formulae by Warner (2007) were used for the R magnitudes.

The initial observations were made by Warner. When it became apparent that a single station could not determine the system parameters because the second period was nearly commensurate with an Earth day, the other observers joined in a collaboration effort. Table II lists the observers, the dates of their observations, and the session numbers (those given in the lightcurve legends).

OBS	Dates (2018 mm/dd)	Sess
BW	07/25-08/06 08-09 30-31	1-15 20 23 28 31
AA	21, 27-28, 31	24-27 30
VB	08/06-08 30	16 19 22 29
JO	08/07-08	18 21
DP	08/08	17

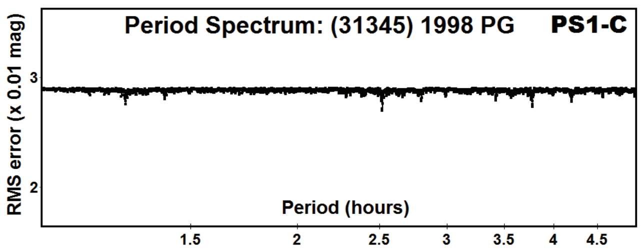
Table II. The observer codes are given in Table I. The Sess column gives the session numbers in the data set. These are listed in the legend for each lightcurve.

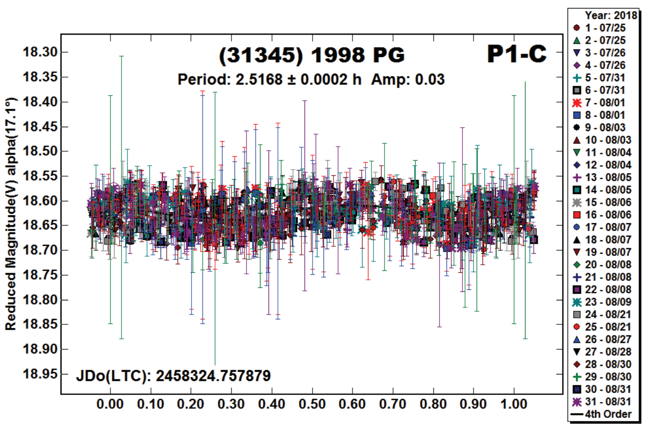
Initial Period Analysis

The initial period analysis was done by Warner using *MPO Canopus*, which incorporates the FALC period search algorithm (Harris et al., 1989). *MPO Canopus* does an iterative dual period search, i.e., finds a dominant period and subtracts it to find the second period; it then subtracts the second period to find the first period again. The process is repeated until the two periods stabilize. This usually works for additive lightcurves such as with 1998 PG. It does not work on complex periods such as those for tumbling asteroids. In that case, and for a better solution for additive lightcurves, custom software by Pravec uses a simultaneous period search (see, e.g., Pravec et al., 2000).

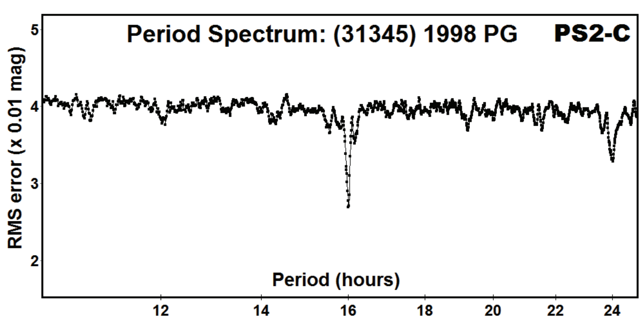
It was apparent that there was a long period component in the data after only the first few observing runs. However, the short period was not very strong and, in fact, almost not existent. When doing the initial dual period analysis with *MPO Canopus*, the short period search was be forced to a range of 2.5-2.56 h, i.e., to include P_1 found by Pravec et al. (2000) since it was considered secure.

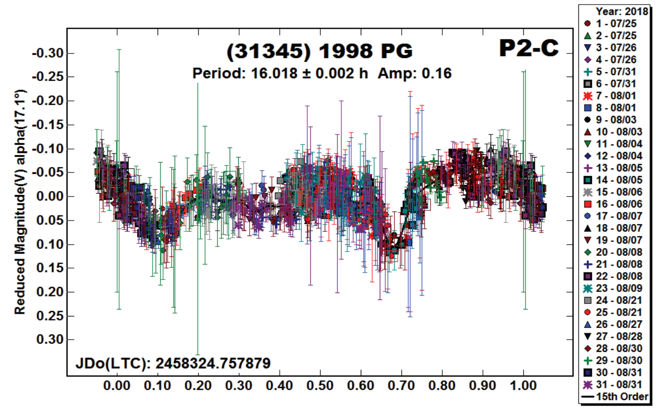
Using the initial value for P_1 from the 2018 data, a secondary period of about 16 hours emerged and, with each additional data set, became more definitive. The same applied to the primary period, although – as seen in the period spectrum for the combined data set (PS1-C) – the solution was weak and stayed that way to the end of the campaign.





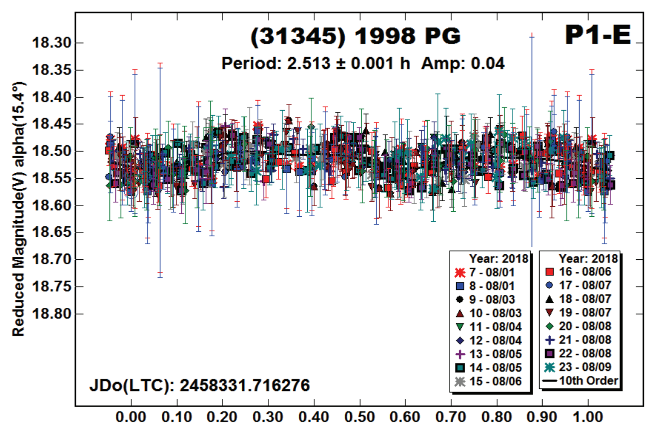
The period for the secondary lightcurve for the combined data set was clearly defined (PS2-C). On first glance, it appeared to show mutual events (occultations and/or eclipses), which would secure the claim of the asteroid being binary. If so, then the presumed satellite rotation was tidally locked to the orbital period. Questions remain, however, about the secondary period solution.

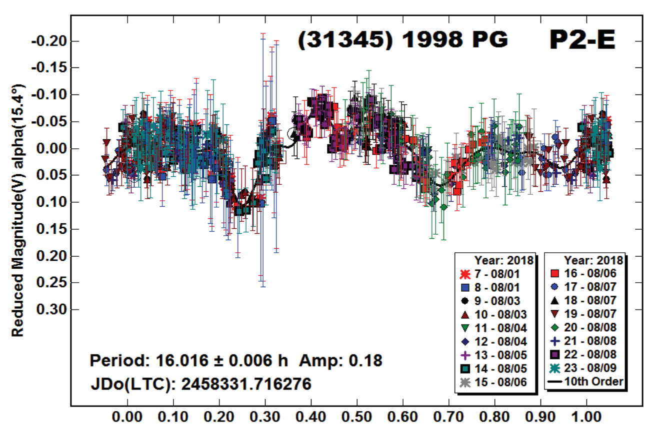




First, the mutual events are not evenly spaced in the orbit. Instead of being 0.5 rotation phase apart, the events are spaced about 0.6 (or 0.4) rotation phase apart. This is possible with the right viewing geometry and if the satellite orbit is sufficiently eccentric, which is very rare. Numerous other periods were tried to see if they would produce a symmetric secondary lightcurve. None did and, as seen in the period spectrum, no solution other than $P_2 = 16.018 \pm 0.002$ h was remotely possible.

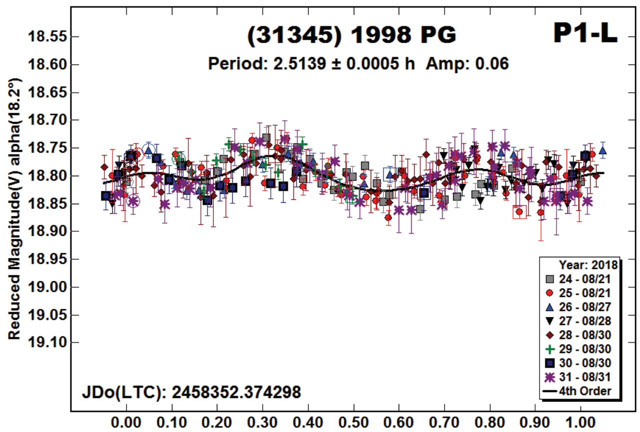
The greatest concern is that Pravec could not get the 1998 data set to fit the 16-hour solution, only those periods originally reported. He was given the 2018 data set and found that the 16-hour solution was very likely. Compounding the problem was that when the 2018 data set was broken into two parts, one before and one after interference from the moon, Pravec found that the lightcurve components had changed. Separate solutions are shown for the "early" (E) and "late" (L) lightcurve plot pairs.

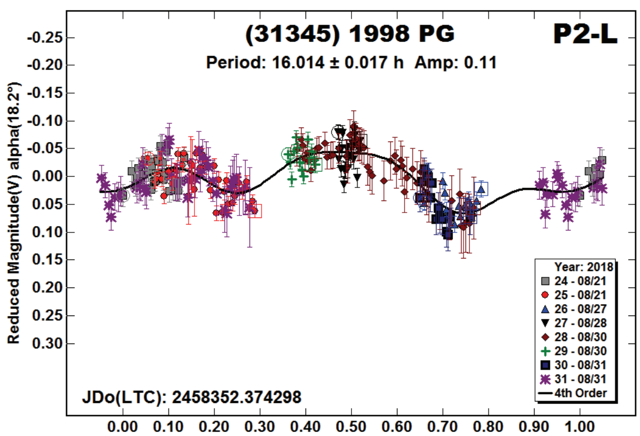




Number	Name	2018 mm/dd	Pts	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.
31345	1998 PG	07/25-08/31	927	17.2,14.8,22.7	319	+13	2.5168	0.0002	0.03	0.01
							16.018	0.002	0.16	0.02
31345	1998 PG	07/25-08/31	696				2.513	0.001	0.04	0.01
							16.016	0.006	0.18	0.02
31345	1998 PG	07/25-08/31	231				2.5139	0.0005	0.06	0.01
							16.014	0.017	0.11	0.02

Table I. Observing circumstances. The three sets of solutions are based on, from top to bottom, the combined data set, the set before the full moon break, and the set after the break. For each pair, the first line gives the results for the primary and the observing aspects. The second line gives the period and amplitude range of the secondary lightcurve. The end phase angle (α) values are for the start and end of the combined data set. The middle value is the lowest phase angle during the period. L_{PAB} and B_{PAB} are each the average phase angle bisector longitude and latitude (see Harris *et al*., 1984).





In particular, the change in the P_2 lightcurve, the less dense data set notwithstanding, makes it possible that it does not actually include mutual events but, instead, is simply due to the rotation of an elongated second body. There just aren't enough high-quality data to say for certain.

Conclusion

The lower primary amplitude in 2018, which was seen at about the same phase angle as in 1998, suggests that the viewing aspect in 2018 was at a higher asteroidcentric latitude, i.e., it was more "pole on" and less "equatorial."

It may be possible that the solutions for P_2 in 1998 and 2018 are both correct. If the changing value of P_2 is due to the rotation of a satellite, 1998 PG could be an example of a system with an asynchronous satellite with unstable rotation. Pravec et al. (2016) found similar behavior for (35107) 1991 VH, which had a different rotation period for the satellite at two different apparitions.

At this time, with the available data, it is not possible to say definitively which secondary period, the one from Pravec et al. (2000) or from this work, is correct or, as just mentioned, both are. It seems very likely that there are at least two bodies in the system. It will take high-quality data from future observations to try to finding secure system parameters.

Looking ahead, the next apparition that is V < 18 is in 2021 December (V ≈ 17.8) but it's not favorable because the galactic latitude will be near 0°. After that, the only apparition through 2050 with V < 18 is in 2041 December (V ≈ 17.1), but that is also at very low galactic latitudes. Anyone with data from the 2018 apparition is encouraged to contact Petr Pravec at the email address in the author's list.

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NEW LIGHTCURVES OF 156 XANTHIPPE, 445 EDNA, AND 676 MELITTA

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Synodic rotation periods and amplitudes are found for 156 Xanthippe 22.132 ± 0.002 hours, 0.22 ± 0.01 magnitudes; 445 Edna 19.974 ± 0.002 hours, 0.27 ± 0.01 magnitudes; 676 Melitta 16.743 ± 0.001 hours, 0.16 ± 0.01 magnitudes.

Observations to obtain the data used in this paper were made at the Organ Mesa Observatory with a 0.35-meter Meade LX200 GPS Schmidt-Cassegrain (SCT) and SBIG STL-1001E CCD. Exposures were 60 seconds, unguided, with a clear filter except where otherwise stated. Photometric measurement and lightcurve construction is with *MPO Canopus* software. To reduce the number of points on the lightcurves and make them easier to read, data points have been binned in sets of 3 with a maximum time difference of 5 minutes.

156 Xanthippe. Previously published rotation periods and amplitudes for 156 Xanthippe are by Debehogne et al. (1982), 22.5 hours, 0.12 magnitudes; Harris and Young (1989), 22.37 hours, 0.12 magnitudes; Behrend (2005), 22.104 hours, 0.10 magnitudes; and Behrend (2006), 22 hours, 0.05 magnitudes in a very sparse lightcurve. New observations on 11 nights 2018 Aug. 28 – Sept. 18 provide a good fit to a lightcurve (Figure 1) with period 22.132 ± 0.002 hours, amplitude 0.22 ± 0.01 magnitudes. This period is broadly compatible with several previous measurements. The amplitude is larger than has been reported previously, suggesting that at 310 degrees celestial longitude the object is in near equatorial presentation. A split halves plot (Figure 2) of the double period 44.294 hours shows that the two halves are nearly identical and rules out the double period.

445 Edna. Two previously published rotation periods for 445 Edna are by Behrend (2001), 9.12 hours in a very sparse lightcurve; and Malcolm, (2002), 19.97 hours with a dense lightcurve at almost the same position in the sky as the current study. Sessions on seven consecutive nights 2018 June 17-23 provide a good fit to a period 19.959 ± 0.003 hours, amplitude 0.27 ± 0.01 magnitudes (Figure 3). Nearly two months before opposition, only about 4.5 hours could be sampled each night. With a period almost exactly 5/6 of Earth's rotation period, nearly half of the double period could not be sampled from a single observatory. Seven more sessions were obtained 2018 Aug. 5-27. These seven sessions provide a good fit to a lightcurve (Figure 4) with period 19.977 ± 0.002 hours, amplitude 0.27 ± 0.01 magnitudes, and a shape as well as period significantly changed from June. With sessions of 6 to 7.5 hours obtained, nearly all of

Number	Name	2018/mm/dd	Pts	Phase	LPAB	BPAB	Period(h)	P.E	Amp	A.E.
156	Xanthippe	08/28-09/18	2219	12.4, 17.6	310	12	22.132	0.002	0.22	0.01
445	Edna	06/17-06/23	1369	15.8, 14.4	309	4	19.959	0.003	0.27	0.01
445	Edna	08/05-08/27	1827	4.1, 10.9	310	10	19.977	0.002	0.27	0.01
767	Melitta	08/30-10/01	1604	8.8, 18.2	318	1	16.743	0.001	0.16	0.01

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