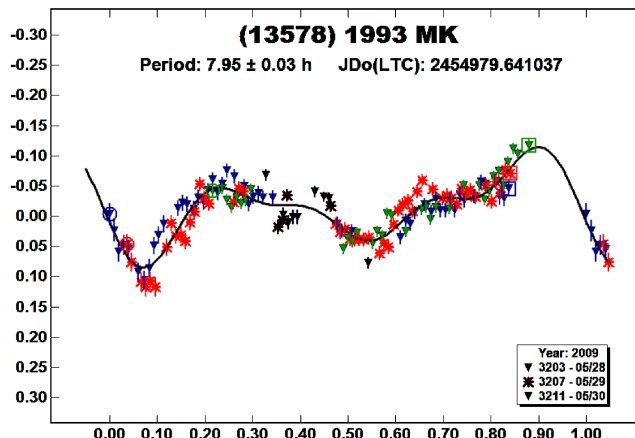
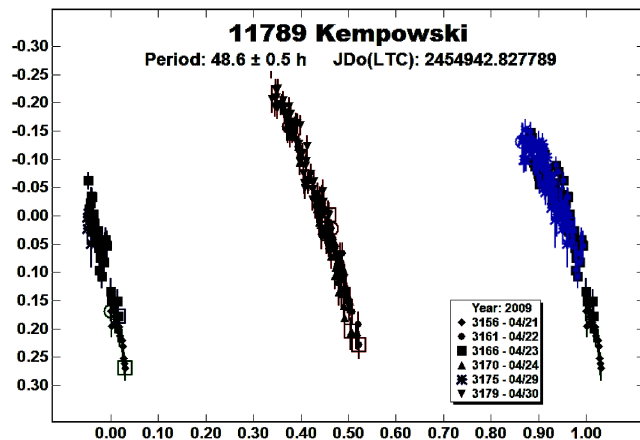
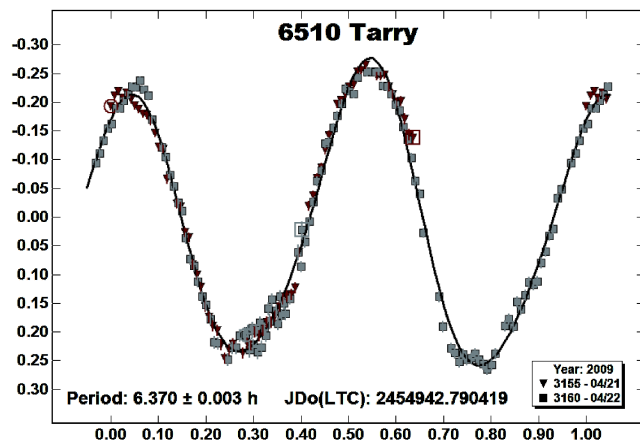
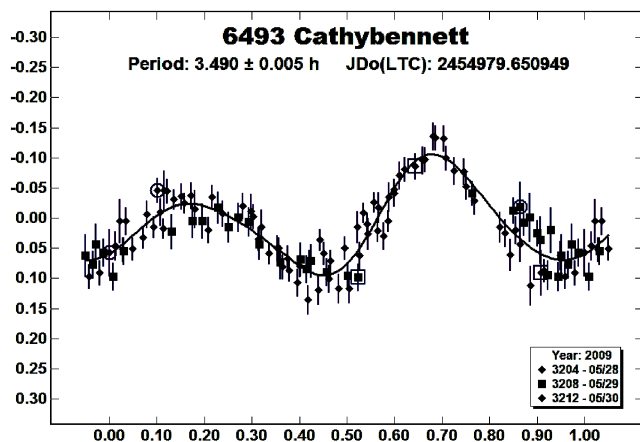
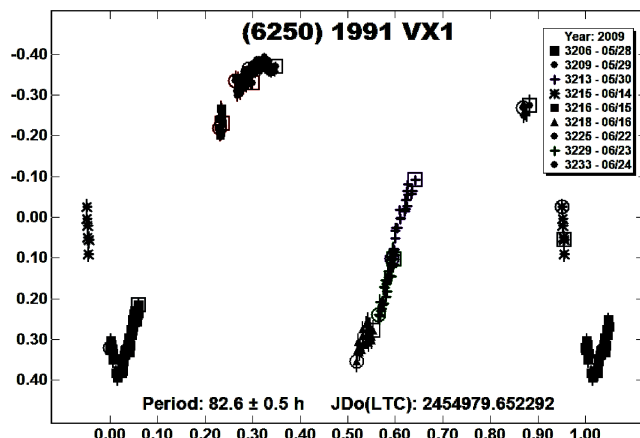




### A RE-EXAMINATION OF THE LIGHTCURVES FOR SEVEN HUNGARIA ASTEROIDS

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(Received: 2009 Jul 2)

During the course of a study of long period asteroids ( $f < 1 \text{ d}^{-1}$ ) within the Hungaria asteroid population, the lightcurves for seven asteroids were re-examined using updated software and techniques. Several were found to have significantly different periods from those previously reported by two of the authors (Warner and Stephens). The most significant change was 2074 Shoemaker, which was initially reported to have a period of 57 h but now appears to be a binary asteroid with a primary period of  $2.5328 \pm 0.0004$  h and a possible orbital period of  $55.52 \pm 0.01$  h. The other asteroids that were re-examined were 1919 Clemence, 3043 San Diego, 3353 Jarvis, 4142 Dersu-Uzala, (20232) 1997 YK, and (101549) 1998 YY2. The re-examination showed once again the importance of placing data on at least an internal system to achieve accurate night-to-night calibrations.

Authors Warner and Harris have conducted a concentrated study on the Hungaria population of asteroids since 2004 with one result being the determination of lightcurve parameters for approximately 130 Hungaria members and the discovery of no less than 7 binary asteroids. Analysis of the rotation rates shows strong excess of “slow rotators”, i.e., those with a period  $> 24$  h (or

frequency,  $f < 1 \text{ d}^{-1}$ ). Warner, Harris, and Pravec are now looking at the distribution of the slow rotators in more detail. Part of that effort has been taking another look at ambiguous or questionable findings found in the early stages of the Hungaria study.

In 2007 Warner derived a set of formulae to convert 2MASS (Neugebauer and Leighton, 1969) J-K magnitudes to the Johnson-Cousins BVRI system (Warner, 2007c). The application of those magnitudes for working long period asteroids was discussed in detail by Stephens (2008). All observations by Warner and Stephens now use this technique to provide accurate ( $<0.05 \text{ mag}$ ) night-to-night calibrations. This has become critical for such work since there was (and still is) a strong temptation to try to fit low amplitude lightcurves artificially by visual inspection when, in fact, the amplitude was due to noise and the overall trend from a given night was actually a very small increase or decrease in brightness. That these multiple sessions were actually small segments of a much longer period lightcurve became obvious only when the night-to-night levels were fixed according to the calibrations and a number of sessions were available.

Warner and Stephens applied the “2MASS method” in *MPO Canopus* (Warner, 2009) by re-measuring images of seven Hungaria asteroids that were observed before the method was available. As a result, the period and amplitudes of several curves changed significantly and a probable new binary asteroid was discovered.

1919 Clemence. The period of this Hungaria asteroid was first reported to be 68.5 h with an amplitude of 0.60 mag. (Warner, 2005). After the new analysis, a period we found a period of  $67.4 \pm 0.1 \text{ h}$  and amplitude of  $0.15 \pm 0.03 \text{ mag}$ . If the Fourier analysis is limited to only 2 orders, the solution is unique. However, higher orders allow for other solutions, including those that involve more than two maxima and minima per cycle. Using the U code rating in the asteroid lightcurve database (LCDB, Warner et al., 2009), we give this U = 2 at best.

2074 Shoemaker. Stephens (2004) reported this Hungaria to have a period of 57.02 h with an amplitude of 0.45 mag. This was based on visually fitting different sessions and presuming the minor variations were noise. It appears instead that this is very likely a newly discovered binary asteroid. The new analysis found a distinct main period of  $2.5328 \pm 0.0004 \text{ h}$  with two suggestive “events” (mutual occultation or eclipses) that appear to be total because of flat bottoms. From these, we found an orbital period of  $55.5 \pm 0.5 \text{ h}$ . The error assumes a circular orbit. If not circular, the error could be 2-3x larger. The orbital period is constrained as much by the absence of events at other times as by the coincidence of the two observed events. Other orbit periods would predict mutual events on other nights where none were observed. Unfortunately, the only gap in coverage of the 55.5 h period falls exactly where one would expect the other (primary?) event to fall. Assuming the events are secondary, the size ratio ( $D_s/D_p$ ) is  $\sim 0.25$ . However, it must be clearly said that the data set is too limited to state these conclusions with certainty. We urge careful observations of this asteroid at the next possible opportunity.

3043 San Diego. Warner (2005) reported a period of 30.72 h and 0.37 mag amplitude. The new analysis shows a much different result with a period of  $105.7 \pm 0.1 \text{ h}$  and amplitude  $\sim 0.6 \text{ mag}$ . If so, the lightcurve shows asymmetrical minimums, which may be an indication that it is tumbling.

3353 Jarvis. The period for Jarvis was first reported to be 40.8 h with an amplitude of 0.10 mag (Warner, 2007a). The new analysis

finds a period of  $202.0 \pm 0.5 \text{ h}$  and amplitude  $\sim 0.6 \text{ mag}$ . This and 3043 San Diego were prime examples of how relying on only visual inspection, i.e., *not* linking data to at least an internal system, can lead to significantly different results.

4142 Dersu-Uzala. The period first reported by Warner (2007b) was 71.2 h with an amplitude of 0.22 mag. We now believe the more likely period is nearly double that,  $140 \pm 3 \text{ h}$ , with a maximum amplitude of 0.65 mag. The significantly different depths of the two minimums may be an indication that the asteroid is tumbling. However, the limited data set prevents stating this and the error in the period with any certainty.

(20231) 1997 YK. Warner (2006) reported a period of 48.2 h and amplitude  $>0.22 \text{ mag}$ . Our new analysis cannot find a unique period. Indications are that this asteroid is in a highly agitated state of tumbling and has a relatively short “primary” period. The plot below shows the complete raw data set with no attempt to force the data to a fixed period. Working with the individual sessions gives considerably different results. For example, when using only the data from Oct. 3, forcing a period of  $\sim 14 \text{ h}$  creates a curve that approximates about 25% of a symmetrical bimodal solution. The Oct. 1 data alone implies a period of around two or more days. A much more extensive data set is needed to fully determine the rotation characteristics.

(101549) 1998 YY29. The new analysis yields  $P = 56.7 \pm 0.1 \text{ h}$ ,  $A = 0.51 \pm 0.03 \text{ mag}$ , which is only a small difference from the original solution of  $P = 56.5 \text{ h}$ ,  $A = 0.70 \text{ mag}$ . If nothing else, the new analysis confirmed both the approximate period and the unusual shape of the lightcurve, the latter possibly indicating that the asteroid is in some state of tumbling. Again, a more extensive data set would be required to fully determine the rotational characteristics.

## Conclusion

While this exercise was important to our study of slowly rotating Hungaria asteroids, we hope that it serves another purpose: to demonstrate the importance of putting data onto at least an internal system in which the observer has confidence and to avoid “fixing” data by artificially adjusting zero points without good justification. It also demonstrates that one should re-evaluate past results as possible or appropriate when new methods or tools become available. That may be time-consuming but getting to “the truth” is never a waste of time.

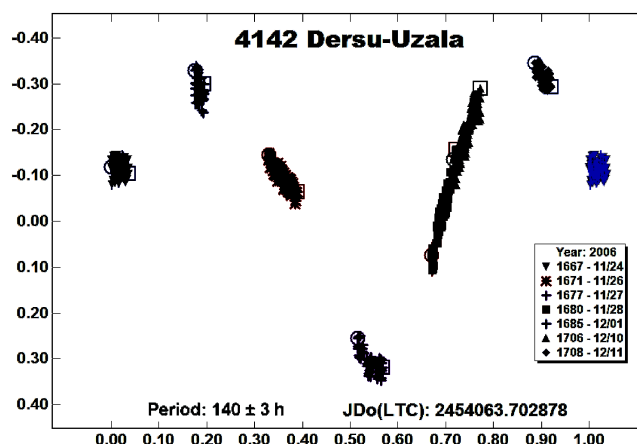
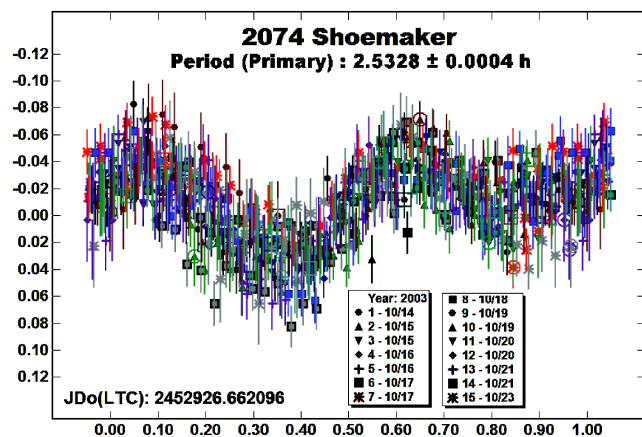
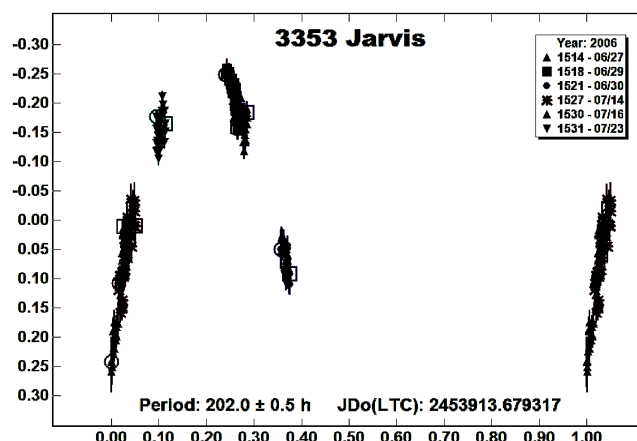
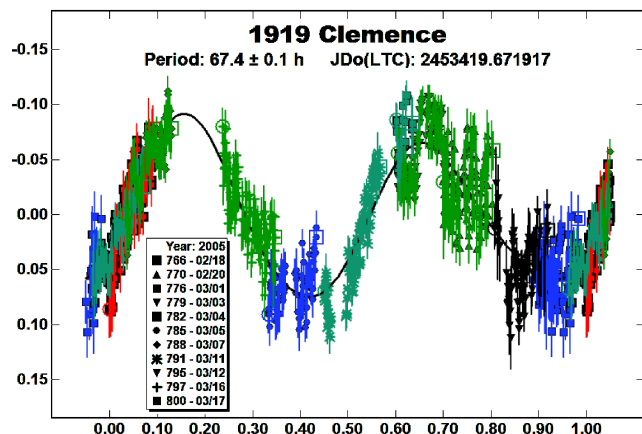
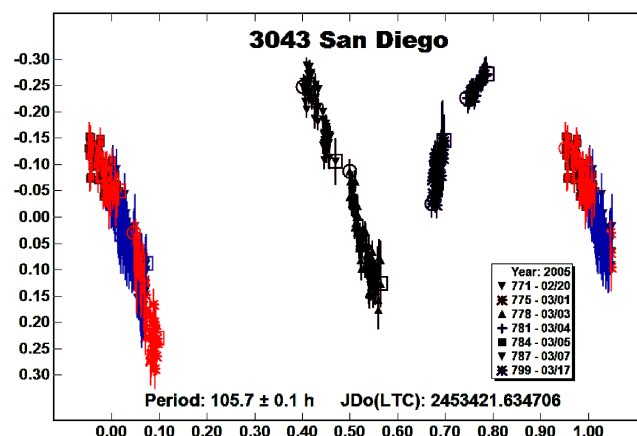
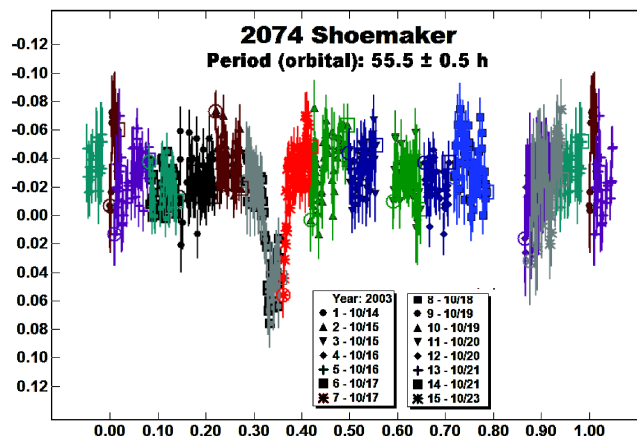
Warner also emphasizes that out of the approximately 140 lightcurves for Hungaria asteroids obtained at the Palmer Divide Observatory, only a very small handful required new analysis. Most of the data were already on an internal system and/or the data for one or more individual sessions were sufficiently conclusive so as to remove ambiguities due to zero point adjustments.

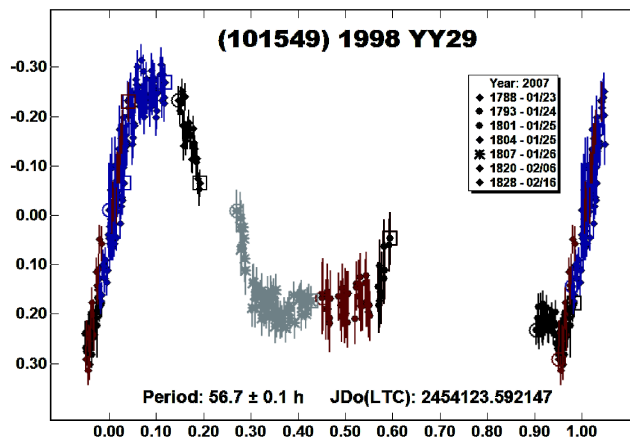
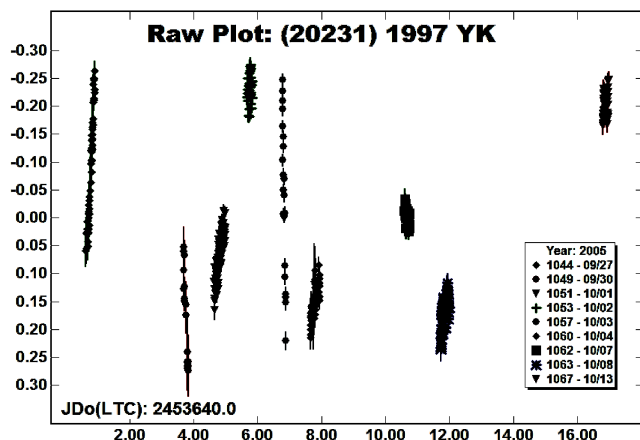
## Acknowledgements

Funding for observations at the Palmer Divide Observatory is provided by NASA grant NNX 09AB48G, by National Science Foundation grant AST-0607505, and by a Gene Shoemaker NEO Grant from the Planetary Society. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

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### ANALYSIS OF THE SLOW ROTATOR (143651) 2003 QO104

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(Received: 2009 Jul 7)

We report on our collaboration to obtain photometric data on the near-Earth asteroid (143651) 2003 QO104 in support of radar observations. Our initial data indicated a slowly rotating asteroid, which allowed radar observers to change their observing schedule accordingly. After obtaining data from 2009 March through April, we were able to determine a synodic period of  $115 \pm 1$  h and amplitude of  $1.60 \pm 0.05$  mag. There are indications that the asteroid may be in non-principal axis rotation, i.e., tumbling.

Observations of the near-Earth asteroid (143651) 2003 QO104 were started by Warner and Carbognani in 2009 mid-March. Stephens contributed data during the campaign to help avoid gaps due to weather and other circumstances. Warner and Stephens linked their observations from night-to-night using the 2MASS (Neugebauer and Leighton, 1969) to BVRI conversions developed by Warner (2007) and applied as described by Stephens (2008).

Initial indications were for a long period, probably  $> 24$  h and amplitude of at least 0.5 mag. As more data became available, it was increasingly obvious that the asteroid had a much longer period and larger amplitude. This proved important to radar observers (Benner, private communications) since the slow rotation would mean higher signal-to-noise values. Accordingly, observing schedules at both Arecibo and Goldstone were changed to obtain additional data. The final data set of photometric observations spanned from 2009 March 17 to April 19. During

that time, all but one session – April 15 – “fell into line.” Disregarding this anomaly, we derived a synodic period of  $114.42 \pm 0.02$  h and amplitude of  $1.60 \pm 0.05$  mag for the  $\sim 1.9$  km diameter asteroid

### Tumbling Considerations

Figure 1 shows the entire lightcurve data set phased to the adopted period of 114.42 h. Note how the April 15 session appears to cover a minimum but is displaced both in time and zero point from the rest of the curve. Figure 2 is a close-up of the plot in Figure 1, showing in more detail the “break-away” April 15 session. If one assumes a minimum was captured, then the vertical displacement (change in zero point) is  $\sim 0.75$  mag and the period that would match it to the minimum covered on March 17 would be 115.5 h. This period would, however, seriously spoil the match-up of other parts of the composite. Such mis-fits in both time and magnitude level are common signs of tumbling. If we adopt that explanation, then the period is not a constant single value; we thus adopt a period of  $115 \pm 1$  h. Exploring the alternate assumption of observational error on April 15, if one removes the first ten or so data points from the session, removing the apparent minimum, then a shift of  $\sim 0.35$  mag brings the session into line with the rest of the curve with the period of 114.42 h. This offset in the zero point is considerably larger than the average error of the calibration method used ( $\sim \pm 0.05$  mag), though offsets that large have been seen under rare circumstances. As a check, the images were measured a second time using a different set of comparison stars. The result was the same apparent capture of a minimum and the large magnitude displacement.

The conclusion from all this is that the April 15 session may be an indication of tumbling since it, being from a second cycle, did not match the curve based on the first cycle. In support of this contention, the maxima and minima are not quite equal, which is another potential sign of tumbling. The lack of overlapping coverage prevents a more certain determination. Had we obtained more data from a second cycle and they also did not match with those from the first, then that would have been almost conclusive evidence of tumbling. Finally, in support of tumbling, the approximate tumbling damping time for the given period and diameter of the asteroid is on the order of 85 Gyr. This is the time that it would take the asteroid to stabilize into single (principal) axis rotation. That is many times longer than the age of the Universe, let alone the Solar System. See Pravec et al. (2005) for a thorough discussion of tumbling asteroids.