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ROTATION PERIOD DETERMINATION FOR 1220 CROCUS

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R.P. Binzel (1985) described two superposed periods for 1220 Crocus on the basis of rather sparse lightcurves: 30.7 days, amplitude 0.87 magnitudes; and 7.90 hours, amplitude 0.15 magnitudes. We have looked for this behavior again with a much denser data set. We find a period of 491.4 hours, amplitude 1.0 magnitudes; a careful search with dual period software finds no evidence of a second period at a level better than 0.1 magnitudes. A color index V-R = 0.47 ± 0.03 is found, and H-G parameters are H = 11.76 ± 0.07 mag, G = 0.05 ± 0.05.

Binzel (1985) made the first photometric lightcurves ever obtained for 1220 Crocus. He reported somewhat sparse lightcurves from 1984 February to May that showed a large amplitude and long period lightcurve with a most likely value of 30.7 days (737 hours). He noted that periods of 20.47 and 15.35 days (491 hours and 368 hours, respectively) were also compatible with his data. His lightcurves of 1984 Feb 7-9 showed a second period of 7.90 hours with an amplitude 0.15 magnitudes. Jacobson and Scheeres (2011) describe how, following rotational spin-up and fissioning, an asteroid binary system can evolve by angular momentum transfer into a system in which the primary acquires a long rotation period and the satellite has a long orbital revolution period around the primary and short rotation period. Warner *et al.* (2015) list 1220 Crocus as one of eight systems in which a slowly rotating primary may have a satellite. The several authors of this paper agreed to collaborate in a search to confirm the existence of the short period and obtain a reliable value for the large amplitude long period.

Observers Vladimir Benishek at Sopot Observatory, Lorenzo Franco at Balzaretto Observatory, Daniel Klinglesmith III and Jesse Hanowell at Etscorn Campus Observatory, Caroline Odden and colleagues at Phillips Academy Observatory, and Frederick Pilcher at Organ Mesa Observatory all contributed lightcurves with clear filters. Table I gives the list of equipment used.

Lead Observer	Telescope	CCD
Benishek	0.35-m *f*/6.3 SCT	ST-8XME
Franco	0.20-m SCT	ST-7XME
Klinglesmith	0.35-m *f*/11 SCT	STL-1001E
Odden	0.40-m *f*/8 R-C	ikon DW436
Pilcher	0.35-m SCT	STL-1001E

Table I. Instruments used for observations. SCT: Schmidt-Cassegrain. R-C: Ritchey-Chretien. ST/STL cameras are from SBIG. The DW436 is from Andor Tech.

The observational strategy was for authors LF and FP to obtain short sessions, usually two hours or less, on as many nights as possible starting 2014 Sep 27, continuing through opposition in 2015 January, and then until late 2015 March. Each session would effectively be a single data point to define the long period but provide no information on the short period. Longer sessions in 2014 December and 2015 January, near opposition when the asteroid was brightest and most favorably placed, would be obtained by all the collaborating observers. The long sessions near minimum lightcurve brightness, when the secondary light variation would be less diluted by the primary light, were examined for a small amplitude short term variability. *MPO Canopus* software was used to measure the images and construct lightcurves; only solar colored stars were used for calibration.

For all calibration stars, the Sloan r' magnitudes as given in the CMC15 catalog (VizieR, 2014) were converted to the Cousins R system by R = r' – 0.22 (Dymock and Miles, 2009). The internal consistency of CMC15 catalog r', J, and K magnitudes is usually better than 0.05 magnitudes. Data points were binned in groups of 3 separated by no more than 5 minutes to reduce the number and make the lightcurve easier to inspect. These data provide a good fit to a lightcurve (Figure 1) phased to period 491.4 ± 0.1 hours with amplitude near 1.0 magnitudes.

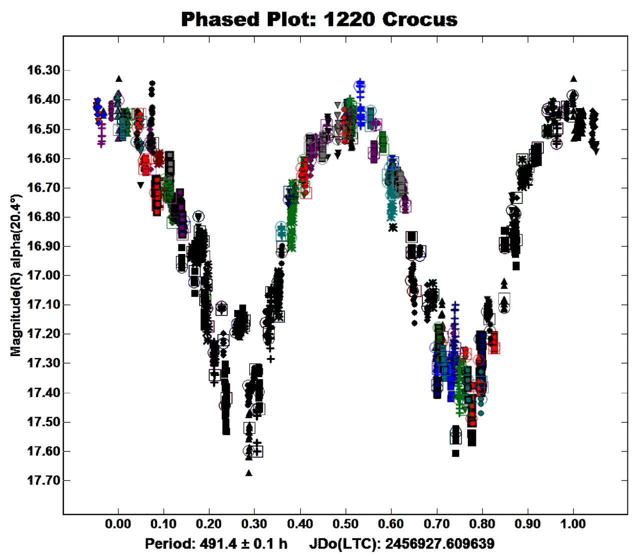

Figure 1. The lightcurve of 1220 Crocus using observations from 2014 Sep 27 - 2015 Mar 26 in R band magnitudes, corrected for changes in phase angle and geocentric and heliocentric distances.

This is exactly 2/3 of Binzel's favored period of 30.7 days (737 hours) and is consistent with his suggested possible period of 20.47 days (491 hours).

A total of 109 short sessions between 20 minutes and 2 hours were obtained between 2014 Sep 27 and 2015 Mar 26. Eleven longer sessions of 3 to 8 hours were obtained between 2014 Dec 16 and 2015 Jan 20. Dual period procedures were employed on these data and found no evidence of a second period with amplitude 0.10 magnitudes or larger. The authors agree that the purported 7.90 hour period with 0.15 magnitude amplitude, found by Binzel (1985), is spurious and the alleged variation results from noise in a sparse data set. This project finds 1220 Crocus to be especially significant as a very slow rotator with no evidence of tumbling.

On 2015 Jan 26-27, author LF obtained alternate images in V and R filters with the goal of obtaining the V-R color index. The same solar colored stars were used for magnitude calibration for both sessions. The CMC15 catalog r' magnitudes were converted to Cousins R magnitudes by R = r' – 0.22. They were converted to Johnson V magnitudes by V = 0.9947r' + 0.6278(J-K), as explained in Dymock and Miles (2009). An upward adjustment of the V magnitude session by 0.47 magnitudes produced best fit to the R magnitude session (Figure 2). Hence we conclude a color index of V-R = 0.47 ± 0.03.

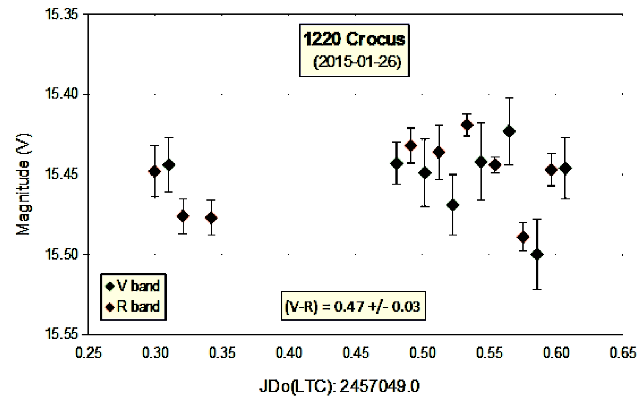

Figure 2. Observations of 1220 Crocus 2015 Jan 26-27 in V and R with R magnitudes adjusted downward by 0.47 mag for best fit.

H-G parameters

For H-G determination, the entire data set (Figure 3) was imported in *Peranso* (Vanmunster, 2014) to evaluate the amplitude variations related to the phase angle.

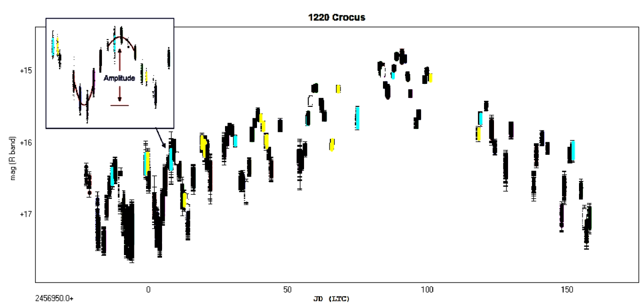

Figure 3. Raw plot of R band magnitudes of 1220 Crocus for entire six-month interval of observations 2014 Sep 27 - 2015 Mar 26.

The empirical formula by Zappala *et al.* (1990) relates the lightcurve amplitude with the phase angle: $A(0°) = A(\alpha)/(1+m\alpha)$, where α is the solar phase angle and m is the slope parameter (0.030 deg^{-1} for S-type objects). For 1220 Crocus we derive from the linear regression analysis

$$m = s/A(0°) = 0.035\ deg^{-1}$$

where s = 0.0216 is the slope of the linear-fit and A(0°) = 0.6155 is the intercept (Figure 4).

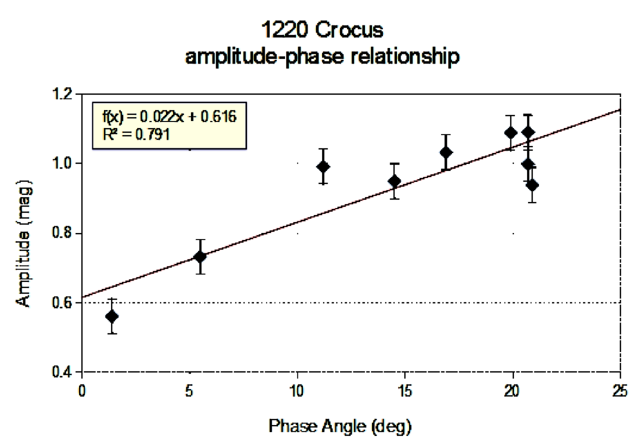

Figure 4. Amplitude-phase relationship for 1220 Crocus.

Due to the large amplitude variations related with phase angle, using, respectively, maximum, minimum and mean light points, we derive different values for H-G parameters (Figure 5).

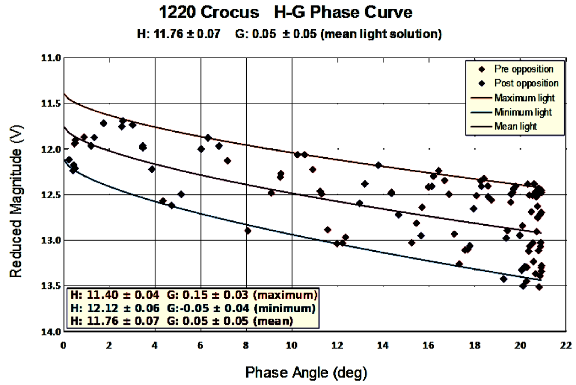

Figure 5. H-G plots for 1220 Crocus for maximum, minimum and mean light data points, respectively.

The V mag values were used by adding the color index V-R = 0.47 to the R mag. For *H-G* determination we choose the mean light values as better representing observation although the maximum light values have a more solid geometric foundation. The mean light values are used in the JPL and MPC databases. The results are $H = 11.76 \pm 0.07$ mag and $G = 0.05 \pm 0.05$.

Our H value is close to $H = 11.72$ published on the JPL Small-Body Database Browser (JPL, 2015), while our value for G is fairly different from the published value of $G = 0.23$. Both our color index (V-R) and G values are compatible with a low- to medium-albedo asteroid (Shevchenko and Lupishko, 1998).

Finally, in Figure 6 we report the fit of the observed data-points with 3rd order Fourier model with phase corrected amplitude.

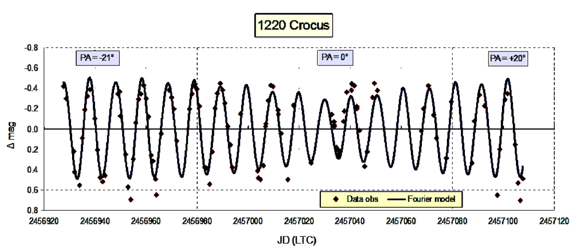

Figure 6. Raw plot of fit of observed data points for 1220 Crocus with 3rd order Fourier model applied to phase corrected amplitude.

Acknowledgments

The authors thank Petr Pravec for analyzing our data and finding no evidence of either a rotating satellite or tumbling behavior. The Etscorn Campus Observatory operations are supported by the Research and Economic Development Office of New Mexico Institute of Mining and Technology (NMIMT). Student support at NMIMT is given by NASA EPSCoR grant NNX11AQ35A, the Department of Physics, and the Title IV of the Higher Education Act from the Department of Education. Author AWH acknowledges support from NASA grant NNX13AP56G and NSF grant AST-1210099.

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[Editorial handling for this manuscript was performed by the Assistant Editor, who notes: The authors are to be congratulated for this finest of examples of a well-conceived and executed collaboration among several observers. Their careful attention to detail in data acquisition and analysis of a difficult target should serve as an inspiration and guide to all those doing asteroid photometry.]

LIGHTCURVE ANALYSIS FOR 30 URANIA

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CCD photometric observations of main-belt asteroid 30 Urania were made over six nights in 2012 January. The lightcurve shows a synodic period of 13.692 ± 0.001 h with an amplitude of 0.19 mag.

Initial photometric observations of main-belt asteroid 30 Urania were made in order to support subsequent occultation observations. The asteroid was predicted to occult the star TYC2 1227-00620-1