A TROOP OF TROJANS: PHOTOMETRY OF 24 JOVIAN TROJAN ASTEROIDS

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(Received: 20 June)

Lightcurves for 24 Jupiter Trojan asteroids were obtained from Cerro Tololo Inter-American Observatory, Lowell Observatory and the Center for Solar System Studies from September 2012 to May 2013.

The Jovian Trojan asteroids are found in orbits near the stable L4 and L5 Langrange points of Jupiter's orbit. They formed further from the Sun than main-belt asteroids and their composition and collisional history appears to be different. As of 2012 15 April, 3402 had been found in the L4 (preceding) region and 1758 in the L5 region. As yet, the rotation properties of Trojan asteroids are poorly known relative to those of main-belt asteroids, due to the lower albedo and greater distance of the Trojans. Here we report lightcurve data for 24 Trojans. Most are in the 50 – 100 km diameter size range.

Observations at the Center for Solar System Studies (CS3) were made by Stephens and Coley with three telescopes, either 0.4-m or 0.35-m SCTs, two using a SBIG STL-1001E CCD Cameras and the other using a SBIG ST-9e CCD camera. All images were unbinned with no filter. Measurements were made using *MPO Canopus*, which employs differential aperture photometry to produce the raw data. Period analysis was done using *MPO Canopus*, which incorporates the Fourier analysis algorithm (FALC) developed by Harris (1989).

Observations at CTIO (Cerro Tololo Inter-American Observation, MPC 807) were made with the CTIO 0.9-m telescope. All images taken at CTIO were unbinned; V and R filters were used. Data and period analysis was done using *MPO Canopus*.

Observations at Lowell Observatory (MPC 688) were made using either the 0.8-m or the Perkins 1.8-m telescopes. All images taken at Lowell were unbinned; V and R filters were used. Data and period analysis was done using *MPO Canopus*.

The results are summarized in Table I. Night-to-night calibration of the data (generally < ±0.05 mag) was done using field stars converted to approximate Cousins R magnitudes based on 2MASS J-K colors (Warner 2007 and Stephens 2008) or using the APASS (AAVSO Photometric All-Sky Survey Release 7). Diameters (Dia) are from the WISE/NEOWISE database (Grav 2012).

With the exception of 5285 Krethon, these targets were selected because they had no previously published rotational results.

2146 Stentor. With an amplitude less than 0.1 mag., the lightcurve is not necessarily bimodal. Monomodal or three or more extrema lightcurves cannot be ruled out.

3391 Sinon. 21 February was observed at CS3. All of the other nights were observed at Lowell using the 31-inch.

4902 Thessandrus. It was clear from early in the observing run that this was the longest period Jovian Trojan yet found. With a rotational period of about a month, it has a high probability of tumbling since the dampening time will exceed the age of the solar system (Pravec 2005). The object was followed for almost two months and the second rotation was markedly different than the first rotation. Petr Pravec (private communication) looked at the data and reported a fit for two periods of 738 h and 510 h, with uncertainties of about 20 hours.

5285 Krethon. Observations were acquired at CS3. Duffard *et al*. (2008) reported a period of 20.84 h. The website containing the lightcurve is no longer available. Our observations could not be phased to the 20.84 h period. Aliases of 16 h and 24 h are not viable solutions.

5436 Eumelos. 27-28 February and 01 March were observed at Lowell using the 0.8-m. Observations were then continued at CS3 after the Lowell observing run was over.

7152 Euneus. Observations were obtained on three consecutive nights and the amplitude did not vary more than 0.01 mag. A period cannot be determined at this opposition and the asteroid should be re-observed at a future opposition.

8125 Tyndareus. Observations over three consecutive nights did not vary more than 0.05 mag. in amplitude. Since observations started very late in the Trojan season, there were not enough available nights to determine a rotational period if it were extremely long.

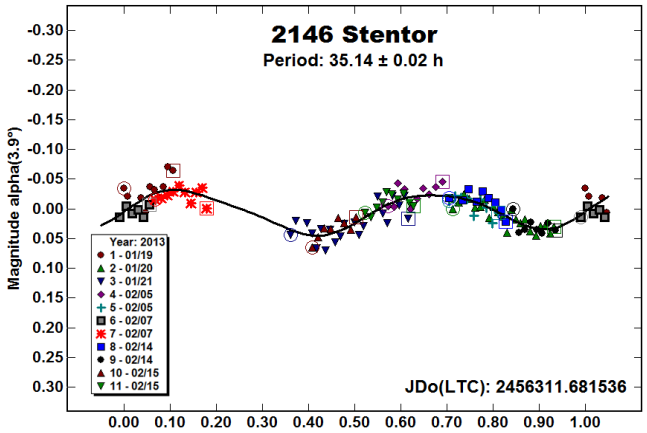
(11351) 1997 TS25. This asteroid has an extremely long rotational period. Despite its size suggesting the damping time is similar to the age of the solar system, no evidence of tumbling was found outside of the catalog star error bars.

13229 Echion. Observations on 06 March were obtained using the 72-inch Perkins telescope at Lowell. The rest of the observing run was lost to a winter storm, so observations were completed at CS3 using the 0.4-m telescope.

(24451) 2000 QS104. Initial observations were obtained at CTIO. When sufficient observations were not obtained to determine a period, they were completed at CS3.

Name	Dates	Obs.	Obs.	Pts	Dia	Phase	L_{PAB}	B_{PAB}	Per.	P.E.	Amp.	AE
2146 Stentor	01/19 – 02/16/13	RDS DRC	CS3	578	51	3.9, 1.0, 2.5	137	5	35.14	0.02	0.08	0.02
3391 Sinon	02/21 – 02/28/13	RDS LMF LHW	LWLL CS3	208	38	2.5, 3.9	142	5	8.14	0.01	0.72	0.03
4068 Menestheus	01/05 – 01/18/13	RDS	CS3	382	68	4.6, 3.9	116	-18	14.341	0.001	0.40	0.03
4501 Eurypylos	03/17 – 4/01/13	RDS	CS3	156	46	4.2, 6.8	158	-9	6.054	0.001	0.24	0.02
4902 Thessandrus	01/21 – 03/16/13	RDS	CS3	1645	51	3.0, 1.3, 8.1	134	-6	738	10	Tumb	
5041 Theotes	03/14 – 03/18/13	DRC	CS3	106		4.4, 5.1	155	9	6.52	0.01	0.35	0.03
5123 1989 BL	02/17 – 02/18/13	RDS	CS3	168	42	4.0, 4.2	132	8	9.88	0.01	0.40	0.02
5284 Orsilocus	02/10 – 02/13/13	RDS	CS3	264	50	3.1, 3.2	141	15	10.31	0.01	0.12	0.02
5285 Krethon	03/04 – 03/22/13	RDS	CS3	210	50	1.9, 4.3	163	10	12.04	0.01	0.46	0.03
5436 Eumelos	02/27 – 03/14/13	RDS LMF LHW	CS3 LWLL	375	38	5.1, 7.9	136	-8	38.41	0.02	0.68	0.03
6545 1986 TR6	03/17 – 3/31/13	RDS	CS3	166	51	4.8, 7.1	156	-12	16.26	0.01	0.31	0.03
7152 Euneus	01/20 – 01/22/13	RDS	CS3	208	40	3.5, 3.1	135	2	Undet			
8125 Tyndareus	04/01 – 04/03/13	RDS	CS3	97	27	5.9, 6.2	162	-5	Undet		<.05	
11351 1997 TS25	03/29 – 5/01/13	DRC	CS3	326	34	4.8, 9.1	167	-12	513.7	1.3	0.53	0.1
12052 Aretaon	09/08 – 09/19/12	RDS	CS3	161	39	2.6, 4.1	341	11	8.05	0.01	0.17	0.02
13229 Echion	03/06 – 03/13/13	LMF FV DRC	CS3 Lwll	204		2.4, 3.9	155	0	8.46	0.01	0.33	0.04
15436 1998 VU30	02/26 – 02/28/13	RDS	CS3	156	88	5.4, 5.7	136	-16	8.97	0.01	0.29	0.03
15440 1998 WX4	01/05 – 01/19/13	RDS	CS3	321	63	5.2, 2.6	131	5	Undet			
15502 1999 NV27	9/20 – 9/22/12	LMF DLR RDS	CTIO	90	53	3.9, 4.2	342	11	15.03	0.03	0.10	0.01
15535 2000 AT177	03/01 – 03/02/13	RDS	CS3	115	40	2.0, 2.2	152	-1	6.01	0.01	0.26	0.03
18046 1999 RN116	09/08 – 11/03/12	RDS	CS3	181	43	1.9, 9.3	352	-6	36.00	0.03	0.13	0.02
19020 2000 SC6	09/16 – 09/21/12	LMF DLR RDS	CTIO	141	43	5.3, 4.9	7	-19	9.82	0.01	0.43	0.02
21601 1998 XO89	04/04 – 04/12/13	RDS	CS3	256	55	6.1, 7.1	174	-22	12.65	0.01	0.30	0.02
24451 2000 QS104	9/20 – 11/04/12	RDS LMF DLR	CTIO CS3	225	41	3.2, 2.3, 7.9	5	-9	40.68	0.04	0.03	0.01

Table I: Observing results.


2146 Stentor
Period: 35.14 ± 0.02 h
Magnitude alpha(3.9°)
Year: 2013
1 - 01/19
2 - 01/20
3 - 01/21
4 - 02/05
5 - 02/05
6 - 02/07
7 - 02/07
8 - 02/14
9 - 02/14
10 - 02/15
11 - 02/15
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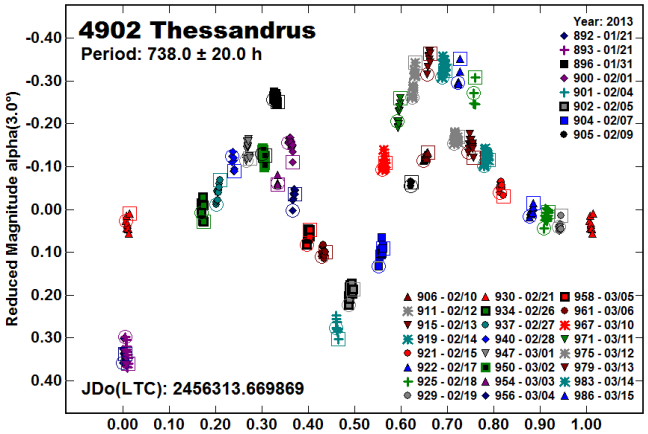
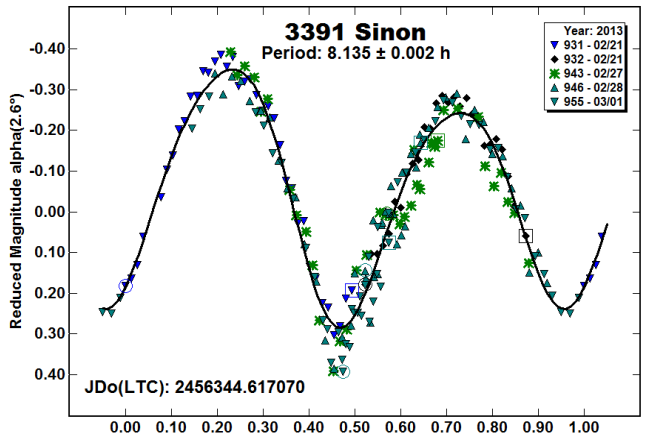
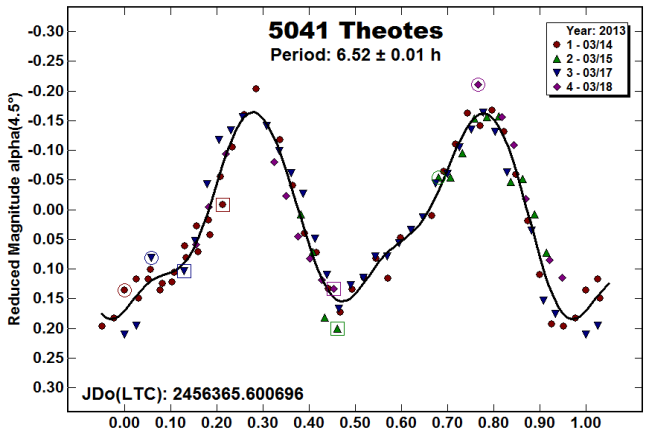
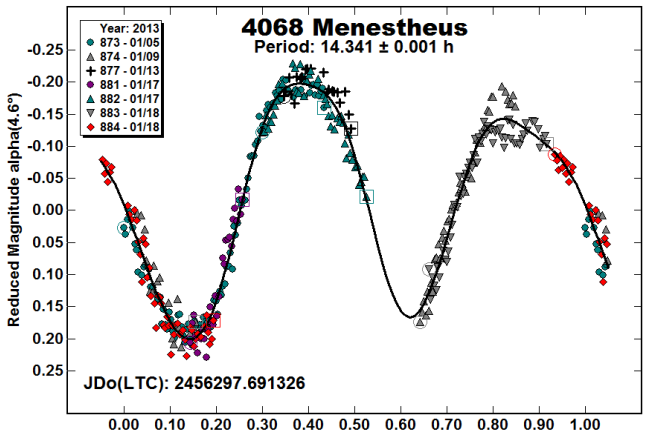
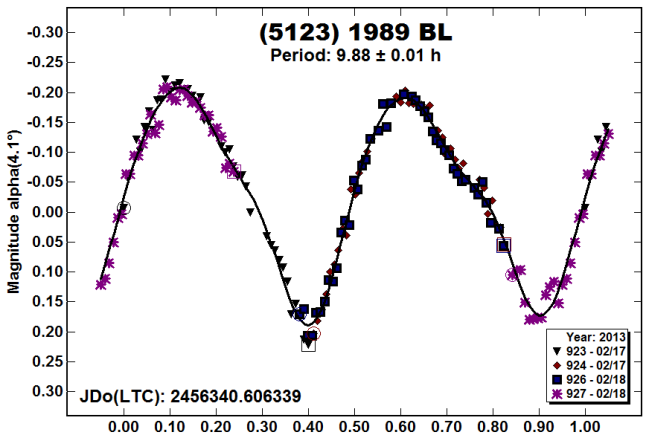
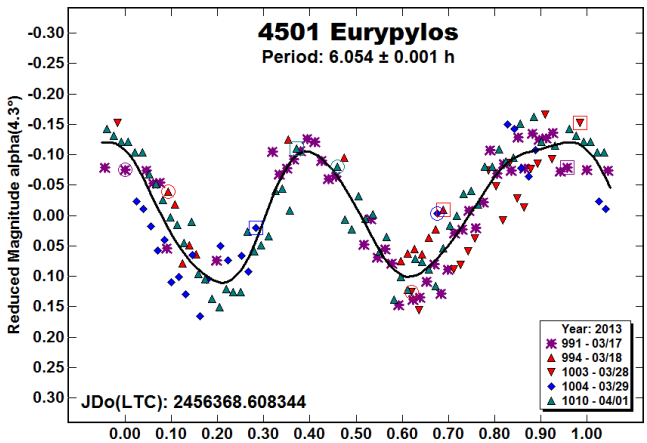

4902 Thessandrus
Period: 738.0 ± 20.0 h
Reduced Magnitude alpha(3.0°)
Year: 2013
892 - 01/21
893 - 01/21
896 - 01/31
900 - 02/01
901 - 02/04
902 - 02/05
904 - 02/07
905 - 02/09
906 - 02/10
911 - 02/12
915 - 02/13
919 - 02/14
921 - 02/15
922 - 02/17
925 - 02/18
929 - 02/19
930 - 02/21
934 - 02/26
937 - 02/27
940 - 02/28
947 - 03/01
950 - 03/02
954 - 03/03
956 - 03/04
958 - 03/05
961 - 03/06
967 - 03/10
971 - 03/11
975 - 03/12
979 - 03/13
983 - 03/14
986 - 03/15
JDo(LTC): 2456313.669869

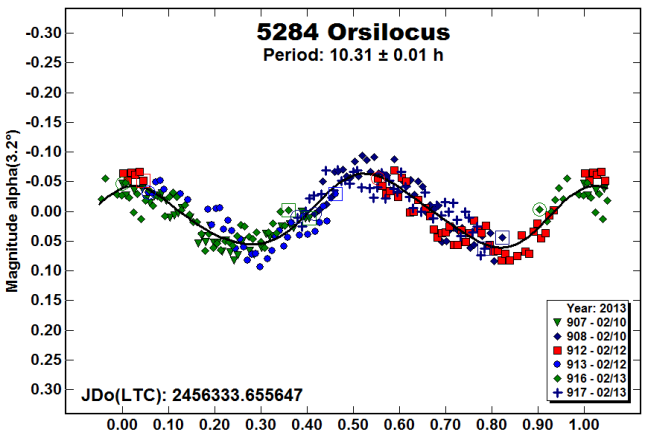

3391 Sinon
Period: 8.135 ± 0.002 h
Reduced Magnitude alpha(2.6°)
Year: 2013
931 - 02/21
932 - 02/21
943 - 02/27
946 - 02/28
955 - 03/01
JDo(LTC): 2456344.617070

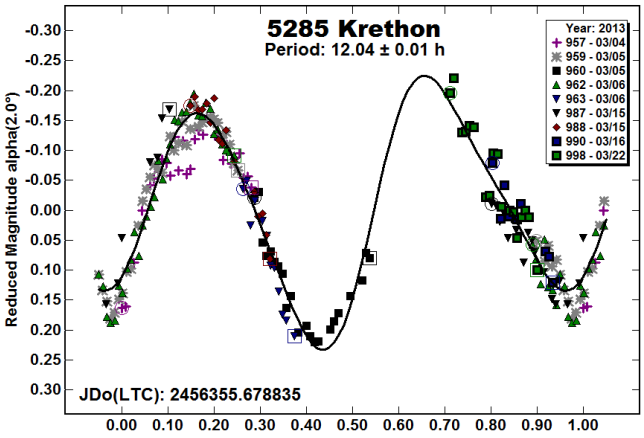

5041 Theotes
Period: 6.52 ± 0.01 h
Reduced Magnitude alpha(4.5°)
Year: 2013
1 - 03/14
2 - 03/15
3 - 03/17
4 - 03/18
JDo(LTC): 2456365.600696

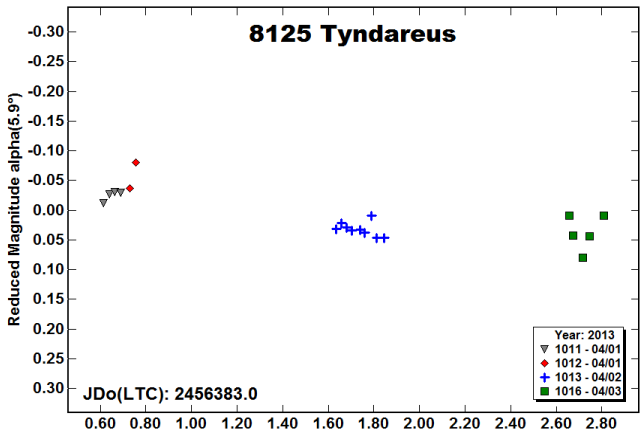

4068 Menestheus
Period: 14.341 ± 0.001 h
Reduced Magnitude alpha(4.6°)
Year: 2013
873 - 01/05
874 - 01/09
877 - 01/13
881 - 01/17
882 - 01/17
883 - 01/18
884 - 01/18
JDo(LTC): 2456297.691326

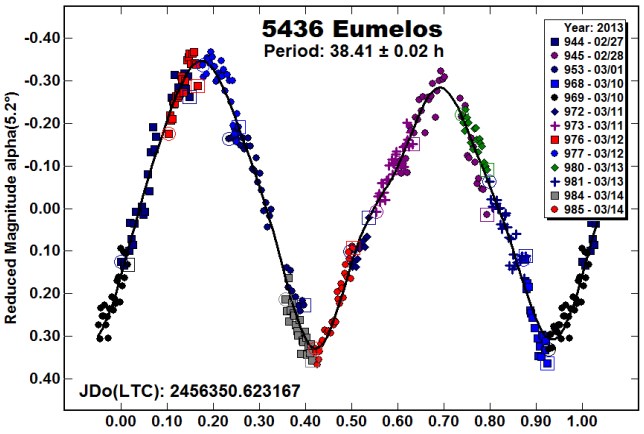

(5123) 1989 BL
Period: 9.88 ± 0.01 h
Magnitude alpha(4.1°)
Year: 2013
923 - 02/17
924 - 02/17
926 - 02/18
927 - 02/18
JDo(LTC): 2456340.606339

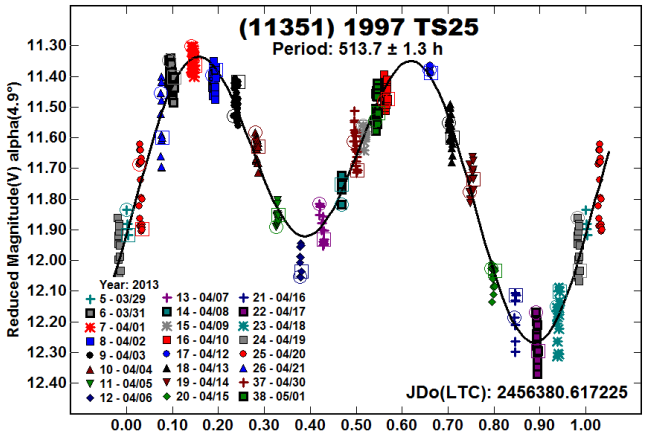

4501 Eurypylos
Period: 6.054 ± 0.001 h
Reduced Magnitude alpha(4.3°)
Year: 2013
991 - 03/17
994 - 03/18
1003 - 03/28
1004 - 03/29
1010 - 04/01
JDo(LTC): 2456368.608344

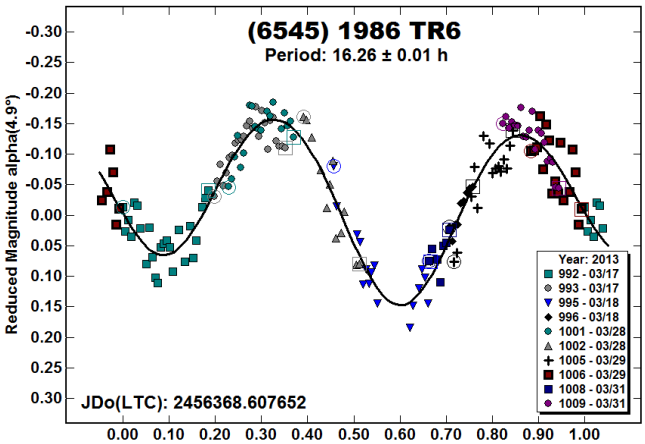

5284 Orsilocus
Period: 10.31 ± 0.01 h
Magnitude alpha(3.2°)
Year: 2013
907 - 02/10
908 - 02/10
912 - 02/12
913 - 02/12
916 - 02/13
917 - 02/13
JDo(LTC): 2456333.655647

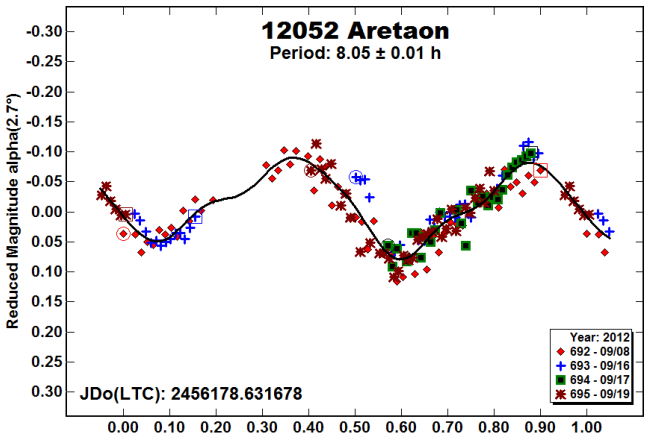

5285 Krethon
Period: 12.04 ± 0.01 h
Reduced Magnitude alpha(2.0°)
JDo(LTC): 2456355.678835
Year: 2013
957 - 03/04
959 - 03/05
960 - 03/05
962 - 03/06
963 - 03/06
987 - 03/15
988 - 03/15
990 - 03/16
998 - 03/22

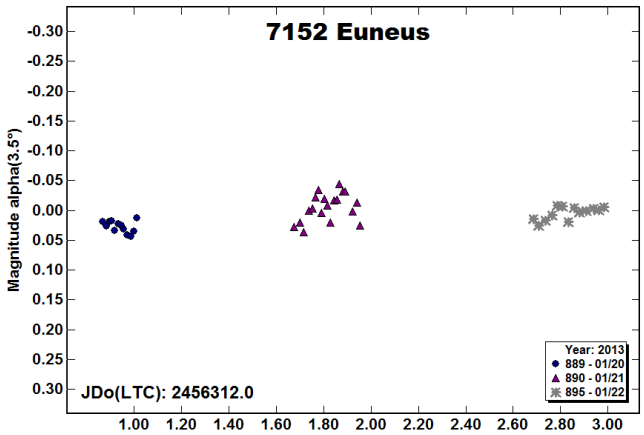

8125 Tyndareus
Reduced Magnitude alpha(5.9°)
JDo(LTC): 2456383.0
Year: 2013
1011 - 04/01
1012 - 04/01
1013 - 04/02
1016 - 04/03

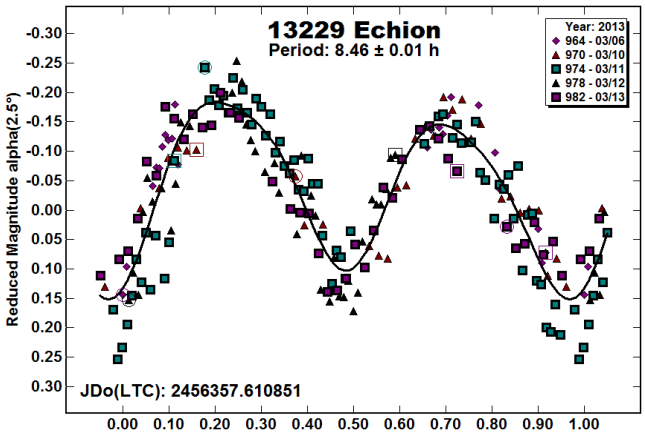

5436 Eumelos
Period: 38.41 ± 0.02 h
Reduced Magnitude alpha(5.2°)
JDo(LTC): 2456350.623167
Year: 2013
944 - 02/27
945 - 02/28
953 - 03/01
968 - 03/10
969 - 03/10
972 - 03/11
973 - 03/11
976 - 03/12
977 - 03/12
980 - 03/13
981 - 03/13
984 - 03/14
985 - 03/14

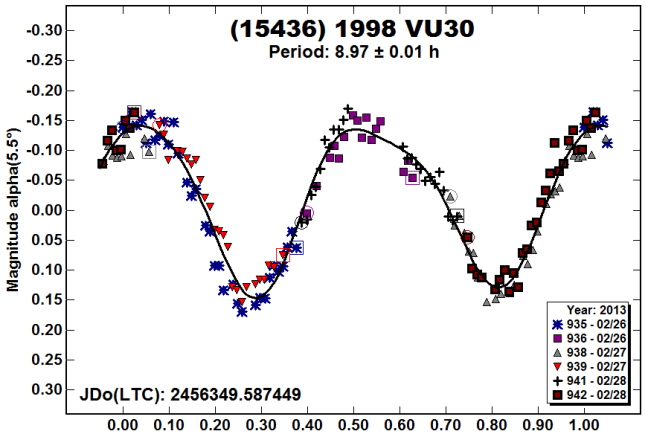

(11351) 1997 TS25
Period: 513.7 ± 1.3 h
Reduced Magnitude(V) alpha(4.9°)
JDo(LTC): 2456380.617225
Year: 2013
5 - 03/29
6 - 03/31
7 - 04/01
8 - 04/02
9 - 04/03
10 - 04/04
11 - 04/05
12 - 04/06
13 - 04/07
14 - 04/08
15 - 04/09
16 - 04/10
17 - 04/12
18 - 04/13
19 - 04/14
20 - 04/15
21 - 04/16
22 - 04/17
23 - 04/18
24 - 04/19
25 - 04/20
26 - 04/21
37 - 04/30
38 - 05/01

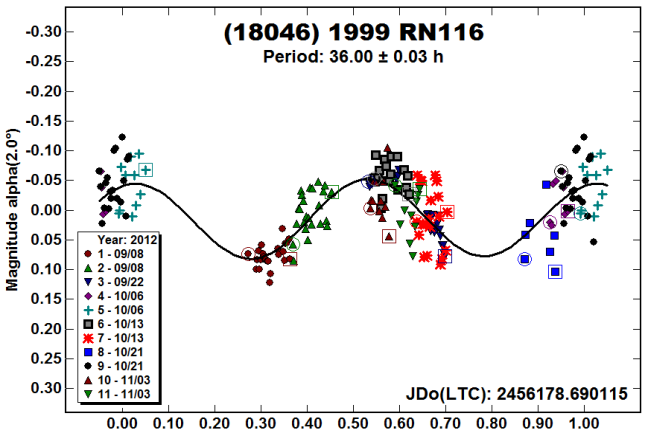

(6545) 1986 TR6
Period: 16.26 ± 0.01 h
Reduced Magnitude alpha(4.9°)
JDo(LTC): 2456368.607652
Year: 2013
992 - 03/17
993 - 03/17
995 - 03/18
996 - 03/18
1001 - 03/28
1002 - 03/28
1005 - 03/29
1006 - 03/29
1008 - 03/31
1009 - 03/31


12052 Aretaon
Period: 8.05 ± 0.01 h
Reduced Magnitude alpha(2.7°)
JDo(LTC): 2456178.631678
Year: 2012
692 - 09/08
693 - 09/16
694 - 09/17
695 - 09/19


7152 Euneus
Magnitude alpha(3.5°)
JDo(LTC): 2456312.0
Year: 2013
889 - 01/20
890 - 01/21
895 - 01/22


13229 Echion
Period: 8.46 ± 0.01 h
Reduced Magnitude alpha(2.5°)
JDo(LTC): 2456357.610851
Year: 2013
964 - 03/06
970 - 03/10
974 - 03/11
978 - 03/12
982 - 03/13


(15436) 1998 VU30
Period: 8.97 ± 0.01 h
Magnitude alpha(5.5°)
JDo(LTC): 2456349.587449
Year: 2013
935 - 02/26
936 - 02/26
938 - 02/27
939 - 02/27
941 - 02/28
942 - 02/28


(18046) 1999 RN116
Period: 36.00 ± 0.03 h
Magnitude alpha(2.0°)
JDo(LTC): 2456178.690115
Year: 2012
1 - 09/08
2 - 09/08
3 - 09/22
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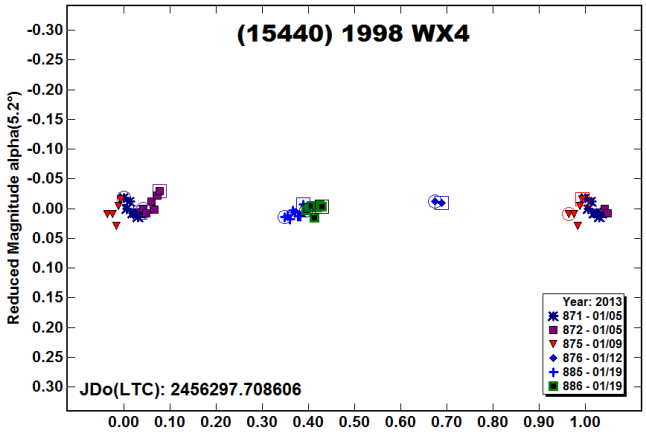
8 - 10/21
9 - 10/21
10 - 11/03
11 - 11/03


(15440) 1998 WX4
Reduced Magnitude alpha(5.2°)
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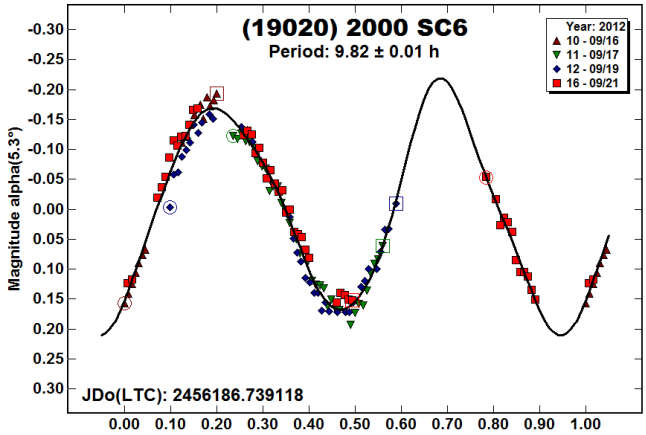
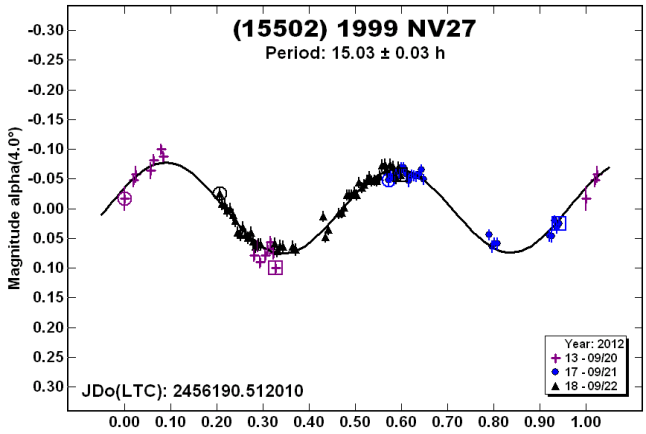
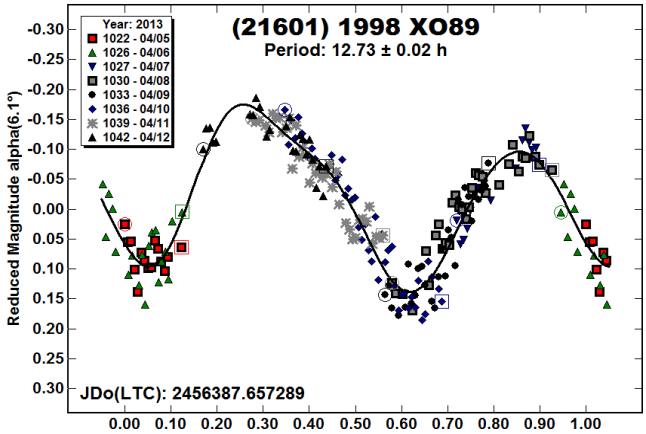
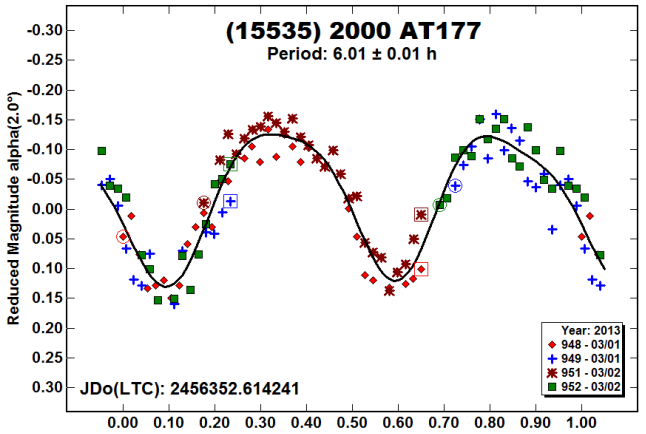
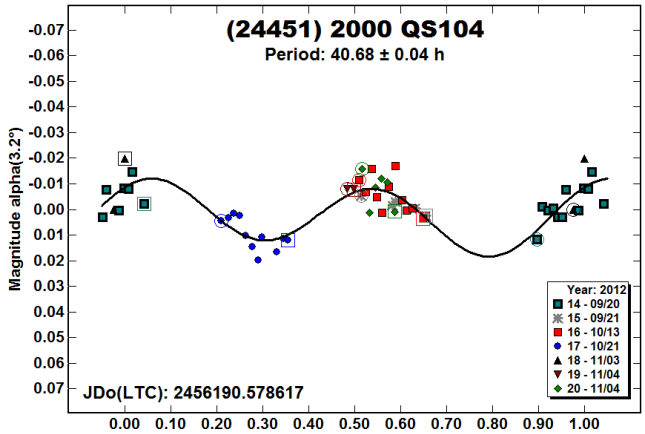
Year: 2013
871 - 01/05
872 - 01/05
875 - 01/09
876 - 01/12
885 - 01/19
886 - 01/19


(19020) 2000 SC6
Period: 9.82 ± 0.01 h
Magnitude alpha(5.3°)
JDo(LTC): 2456186.739118
Year: 2012
10 - 09/16
11 - 09/17
12 - 09/19
16 - 09/21


(15502) 1999 NV27
Period: 15.03 ± 0.03 h
Magnitude alpha(4.0°)
JDo(LTC): 2456190.512010
Year: 2012
13 - 09/20
17 - 09/21
18 - 09/22


(21601) 1998 XO89
Period: 12.73 ± 0.02 h
Reduced Magnitude alpha(6.1°)
JDo(LTC): 2456387.657289
Year: 2013
1022 - 04/05
1026 - 04/06
1027 - 04/07
1030 - 04/08
1033 - 04/09
1036 - 04/10
1039 - 04/11
1042 - 04/12


(15535) 2000 AT177
Period: 6.01 ± 0.01 h
Reduced Magnitude alpha(2.0°)
JDo(LTC): 2456352.614241
Year: 2013
948 - 03/01
949 - 03/01
951 - 03/02
952 - 03/02


(24451) 2000 QS104
Period: 40.68 ± 0.04 h
Magnitude alpha(3.2°)
JDo(LTC): 2456190.578617
Year: 2012
14 - 09/20
15 - 09/21
16 - 10/13
17 - 10/21
18 - 11/03
19 - 11/04
20 - 11/04

Period Analysis

To avoid observation bias, asteroids were followed even if they were long period. Three had to be abandoned for the current observing season due to their low amplitude light curves.

Acknowledgements

French, Stephens and La Rocca were visiting astronomers at Lowell Observatory and at Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatory, operated by the Association of Universities for Research in Astronomy, under contract with the National Science Foundation. The Cerro Tololo 0.9-m telescope is operated by the SMARTS Consortium. French, Vilas and Stephens were visiting astronomers at Lowell Observatory. This research was supported by National Science Foundation grant AST-1212115.

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A PLETHORA OF PHOCAEA ASTEROIDS

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(Received: 29 June)

CCD photometric observations of three Phocaea family asteroids were obtained from the Center for Solar System Studies in 2013 June. 5040 Rabinowitz has a period of 4.691 ± 0.001 h and an amplitude of 0.35 ± 0.02 mag. while 6487 Tonyspear has a period of 74.91 ± 0.02 h and an amplitude of 1.24 ± 0.02 mag., and (70126) 1999 NT2 has a period of 5.41 ± 0.01 h and an amplitude of 0.83 ± 0.03 mag.

The Center for Solar System Studies (CS3) recently started operations. Its participants have a history of studying asteroid families such as Jovian Trojans or Hungarias. When program members of targeted families are not observable, alternative targets such as Near-Earth Objects or the Phocaea family will be selected. No previous periods for these asteroids are reported in the Lightcurve Database (Warner 2013).

Stephens used either a 0.4-m or 0.35-m SCT with a FLI-1001e, SBIG STL-1001E CCD camera while Coley used a 0.35-m SCT with a SBIG ST-9e CCD camera. All images were unbinned with no filter and had Master flats and darks applied to the science frames prior to measurement. Measurements were made using *MPO Canopus*, which employs differential aperture photometry to produce the raw data. Period analysis was done using *MPO Canopus*, which incorporates the Fourier analysis algorithm (FALC) developed by Harris (1989). Night-to-night calibration of the data (generally < ±0.05 mag) was done using field stars converted to approximate Cousins R magnitudes based on 2MASS J-K colors (Warner 2007). The Comp Star Selector feature in *MPO Canopus* was used to limit the comparison stars to near solar color.

5040 Rabinowitz. This asteroid was observed by Coley and Stephens in a crowded star field, which increased the scatter in the plot from dim field stars in the background. Because of this, slight deviations from the Fourier curve were not considered compelling evidence of attenuation events. The average phase angle over the observing run was 21 degrees and the average phase angle bisector Longitude (L_{PAB}) was 271 degrees.

6487 Tonyspear. This asteroid observed by Stephens was also in a crowded star field. The lightcurve profiles with U-shaped maxima and V-shaped minima, the long rotational period and the 'shoulders' on the deepest minimum are suggestive that the asteroid might be a contact binary. The average phase angle over the observing run was 29 degrees contributing to the large amplitude of 1.24 mag. The average phase angle bisector Longitude (L_{PAB}) was 281 degrees.

(70126) 1999 NT2. Also embedded deep in the Milky Way, this asteroid was observed by Stephens. The first night had the densest coverage of observations as it passed in front of a dark nebula near Bernard 133. Subsequent nights were hampered by the dense star fields with over half the images lost to background stars. The Phase Angle was 13 degrees and the phase angle bisector Longitude (L_{PAB}) was 282 degrees.

Acknowledgements

The purchase of the FLI-1001E CCD camera by Stephens was made possible by a 2013 Gene Shoemaker NEO Grant from the Planetary Society.