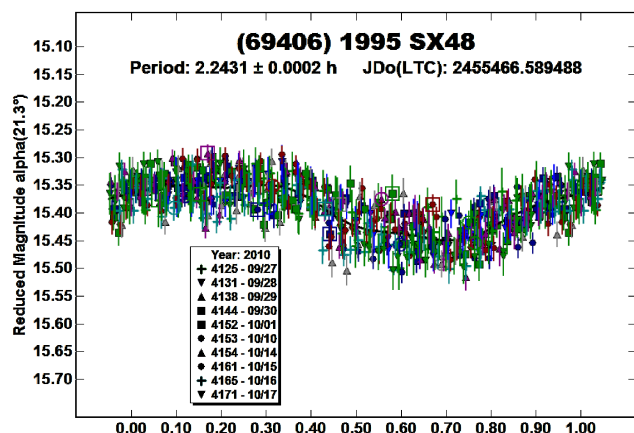
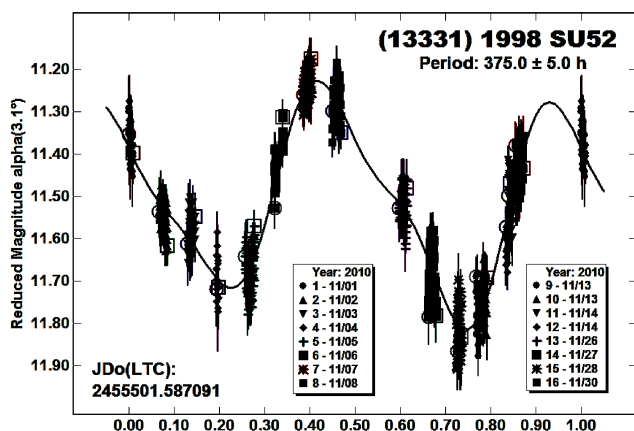
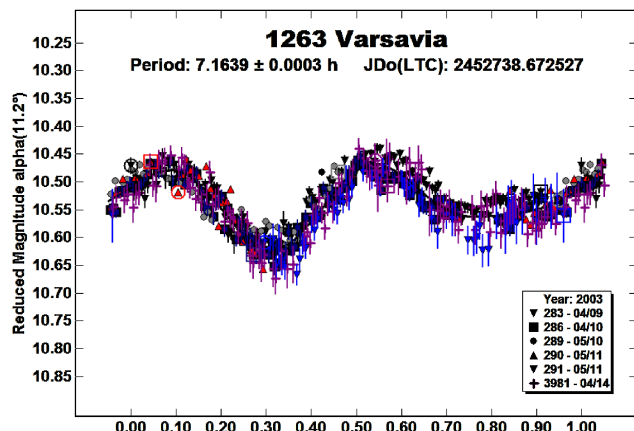


$P < 5$ h, $A < 0.25$ mag, $D < 10$ km). Analysis of the final data set of 625 data points yielded a period of $P = 2.2431 \pm 0.0002$ h and $A = 0.13 \pm 0.01$ mag but no evidence of mutual events (occultations and/or eclipses) or a second period that could be attributed to a satellite. A period of $P = 4.4861 \pm 0.0002$ h, with resulting bimodal solution and amplitude also $A = 0.13$ mag, cannot be formally excluded and, in fact, is just about as likely.



Acknowledgements

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Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

References

- Neugebauer, G. and Leighton, R.B. (1969). Two-micro Sky Survey: A Preliminary Catalog. NASA.
- Stephens, R.D. and Warner, B.D. (2004). *Minor Planet Bul.* **31**, 24-25.
- Stephens, R.D. (2008). "Long Period Asteroids Observed from GMARS and Santana Observatories." *Minor Planet Bul.* **35**, 21-22.
- Warner, B.D. (2007b). "Initial Results from a Dedicated H-G Project." *Minor Planet Bul.* **34**, 113-119.
- Zacharias, N., Urban, S.E., Zacharias, M.I., Wycoff, G.L., Hall, D.M., Monet, D.G., and Rafferty, T.J. (2004). "The second US Naval Observatory CCD Astroglyph Catalog (UCAC2)." *Astrophysical Journal* **127**, 3043-3059.

PHOTOMETRIC OBSERVATIONS AND ANALYSIS OF 1082 PIROLA

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CCD observations of the main-belt asteroid 1082 Pirola were recorded during the period 2010 October to 2011 January. Analysis of the lightcurve found a synodic period of $P = 15.8525 \pm 0.0005$ h and amplitude $A = 0.53 \pm 0.01$ mag. The phase curve referenced to mean magnitude suggests the absolute magnitude and phase slope parameter: $H = 10.507 \pm 0.014$ mag; $G = 0.080 \pm 0.016$. The phase curve referenced to maximum light suggests: $H = 10.320 \pm 0.013$ mag; $G = 0.107 \pm 0.016$.

Our collaborative observing campaign was conducted with a variety of telescopes and CCDs. Baker recorded observations at Indian Hill Observatory (IHO) using a 0.3-m Schmidt-Cassegrain telescope (SCT) reduced to f/5.1 coupled with an SBIG ST-402ME CCD. Pilcher recorded observations at Organ Mesa Observatory (OMO) using a 0.35-m SCT at f/10 coupled with an SBIG STL-1001E CCD. Benishek recorded observations at the Belgrade Astronomical Observatory (BAO) using a 0.40-m SCT at f/10 coupled with an SBIG ST-10XME CCD. In addition to the instruments at our local observatories, Baker recorded observations with robotic telescopes located at the Tzec Maun Observatory

(TMO) near Mayhill, NM, including a 0.4-m Ritchey-Chretien Telescope (RCT) at f/9 coupled with an SBIG STL-6303E CCD and a 0.35-m Maksutov-Newtonian telescope (MNT) at f/3.9 coupled with an SBIG ST-10ME CCD. All images recorded during the observing campaign were calibrated with dark and flat field frames.

Unfiltered observations were recorded at IHO, OMO and BAO local observatories during 17 separate time series sessions (Table I). *MPO Canopus* software (BDW Publishing, 2010) was used by all authors to perform differential photometry and period analysis. The data were binned in sets of 3 with a maximum time interval of 5 minutes. The bimodal composite lightcurve (1) suggests period $P = 15.8525 \pm 0.0005$ h, and amplitude $A = 0.53 \pm 0.01$ mag (Figure 1). Since the amplitude changed during the apparition, we also constructed lightcurves using 2 subsets of the observing sessions. Composite lightcurve (2A) is from time series sessions 1-14, when the phase angle (α) was between -9 and +3 degrees (Figure 2). Composite lightcurve (2B) is from the time series sessions 15-17, when phase angle $\alpha > 12$ degrees (Figure 3).

Phase Curve and H-G Parameters

Individual CCD observations with Bessel V filters were recorded throughout the apparition (Table I) and used to construct the phase curves. Standard V magnitudes of the asteroid were derived from the instrumental magnitudes using differential photometry. Formula 1 was used to estimate the standard V magnitudes of the comparison stars

$$V = 0.628*(J-K) + 0.995*r' \quad (1)$$

where V is the estimated standard V band magnitude, J and K are magnitude bands from the Two-Micron All-Sky Survey, and r' is a magnitude band from the Sloan Digital Sky Survey (Dymock and Miles, 2009).

Depending on the field of view in our images, 5 to 20 stars of the proper color were usually available for use as comparisons and whose calculated standard V magnitudes were reasonably consistent with their corresponding instrumental magnitudes. The comparison star selection and data reduction were performed with *Astrometrica* software (Raab, 2010). The overall error stated for each data point in the table is a combination of the error as a function of the signal to noise ratio and the measure of the uncertainty in the comparison star magnitudes.

The observed magnitude of the asteroid in each observation was corrected for the varying brightness due to rotation by comparing the point on the lightcurve at the time of each observation with both mean magnitude and maximum light. Brightness variance due to changing orbital geometry was also removed by calculating reduced magnitudes with formula 2:

$$V_r = V_o - 5.0 \log(R/r) \quad (2)$$

where V_r is the reduced magnitude, V_o is the observed magnitude, R is the Sun-asteroid distance, and r is the Earth-asteroid distance, both in AU (Warner, 2007). The Lightcurve Ephemeris and H-G Calculator utilities in *MPO Canopus* greatly facilitated this process.

The amplitude corrections for all data point observations were referenced to the mean magnitude in lightcurve (1). The resulting phase curve (A) indicates the absolute magnitude $H = 10.507 \pm 0.014$ mag, and the phase slope parameter $G = 0.080 \pm 0.016$ (Figure 4). However, since the lightcurve data show that the

amplitude changed during the apparition, we note that the mean magnitude might not be the best reference for the amplitude corrections. So, using lightcurves 2A and 2B, we referenced the amplitude corrections for all data points to maximum light. In this case, data points recorded when $\alpha \leq 11$ degrees were corrected using lightcurve (2A). Data points recorded when $\alpha > 11$ degrees were corrected using lightcurve (2B). The resulting phase curve (B) indicates the absolute magnitude $H = 10.320 \pm 0.013$ mag, and the phase slope parameter $G = 0.107 \pm 0.016$ (Figure 5). We note that the larger amplitude corrections referenced to maximum light at the higher phase angles tend to reduce the slope of the curve, resulting in the corresponding increase in the G value.

We found no previous observational data in the literature for the asteroid's period, amplitude, and H-G parameters. However, according to the Planetary Data System (Neese, 2010), 1082 Pirola is a member of the C taxonomic class (Tholen, 1989). The Supplemental IRAS Minor Planet Survey (Tedesco *et al.*, 2002) indicates the asteroid's absolute magnitude, albedo, and diameter to be 10.41 mag, 0.0655, and 43.01 km, respectively. Correlation studies by Harris (1989) shows that members of the C taxonomic class are part of a group with albedo $p_v = 0.058 \pm 0.004$ and mean phase slope parameter $G = 0.086 \pm 0.015$.

The relation $a/b = 10^{(0.4dm)}$ is often used to estimate the equatorial elongation of an asteroid from the amplitude of variation, dm. This relation follows directly from the definition of geometric scattering at zero phase angle and equatorial viewing direction. Generally, the amplitude of variation is larger at increasing phase angle, and smaller at non-equatorial viewing aspect, so the above relation is only an approximation, roughly valid when the viewing direction is not too far off equatorial and the phase angle is not large, say less than 15 degrees or so (A.W. Harris, private communication).

We estimate dm to be 0.47 mag at minimum α . Therefore the equatorial elongation is calculated to be 1.54 using this relation. Since we do not know the viewing direction, the ratio of maximum to minimum equatorial radii must be expressed ≥ 1.54 .

Based on the absolute magnitude derived from our observations, and the albedo value from SIMPS, we calculate the diameter of 1082 Pirola to be 45 kilometers with the formula 3:

$$\log D = 3.125 - 0.2H - (0.5 * \log(p_v)) \quad (3)$$

where D is the diameter (km), H is the absolute magnitude and p_v is the geometric albedo in the V band (Warner, 2007).

Acknowledgements

We wish to thank the Tzec Maun Foundation for the use of their robotic telescopes during this project. We express our appreciation to Alan W. Harris, Brian D. Warner, and Richard Miles for their advice, especially with regards to extrapolating observed magnitudes to maximum light.

References

- BDW Publishing (2010). *MPO Canopus Software*, version 10.2.0.2. <http://www.minorplanetobserver.com>
- Harris, A.W. (1989). "The H-G Asteroid Magnitude System: Mean Slope parameters." *Lunar Planetary Science* **XX**, 375-376.
- Dymock, R. and Miles, R. (2009). "A method for determining the V magnitude of asteroids from CCD images." *Journal of the British Astronomical Association* **119**, 149-156.

Raab, H. (2010). *Astrometrica* Software, version 4.6.5.390
<http://www.astrometrica.at>

Neese, C., Ed., Asteroid Taxonomy V6.0. EAR-A-5-DDR-TAXONOMY-V6.0. NASA Planetary Data System, 2010.
<http://sbn.psi.edu/pds/resource/taxonomy.html>

Tedesco, E.F., Noah, P.V., Noah, M., and Price, S.D. (2002). "The Supplemental *IRAS* Minor Planet Survey." *Astron. J.* **123**, 1056-1085.

Tholen, D. (1989). "Asteroid Taxonomic Classifications," in *Asteroids II*, R.P. Binzel, T. Gehrels, M.S. Matthews, ed. pp 1139-1150. University of Arizona Press, Tucson.

Warner, B.D. (2007). "Initial Results from a Dedicated H-G Project." *Minor Planet Bulletin* **34**, 113-119.

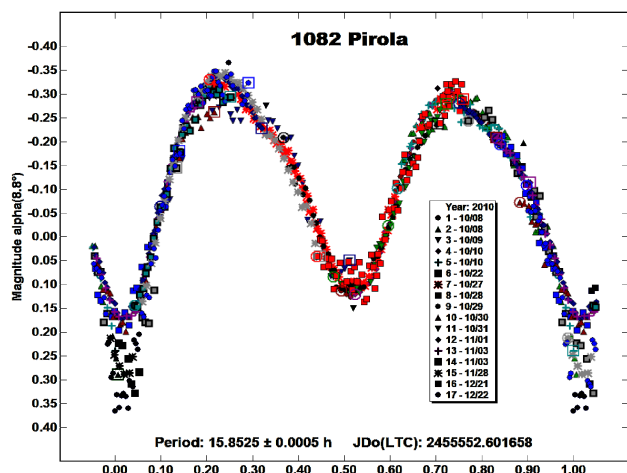


Figure 1. 1082 Pirola composite lightcurve.

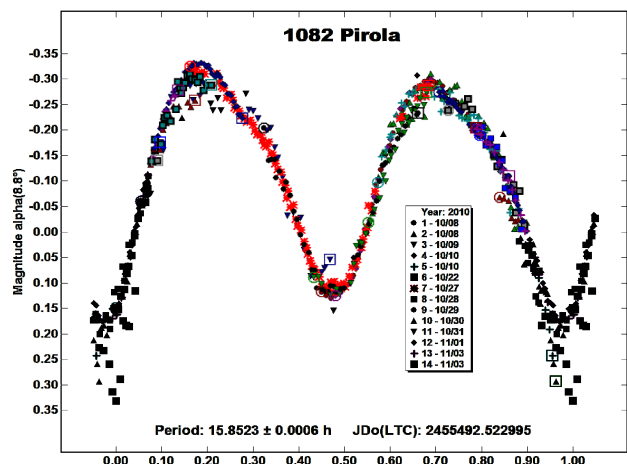


Figure 2. 1082 Pirola composite lightcurve at $-9 < \alpha < +3$ degrees.

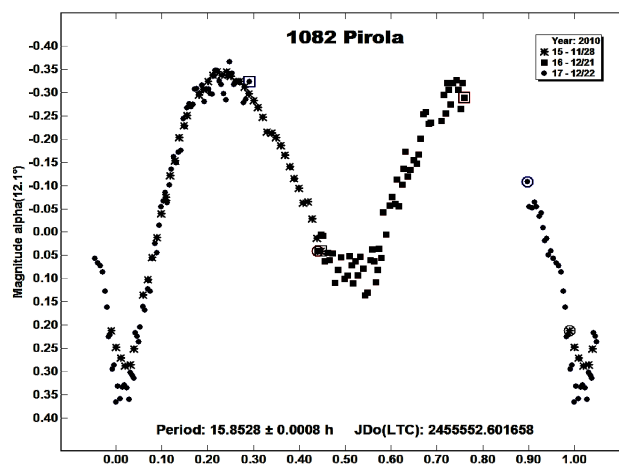


Figure 3. 1082 Pirola composite lightcurve at $\alpha > +12$ degrees.

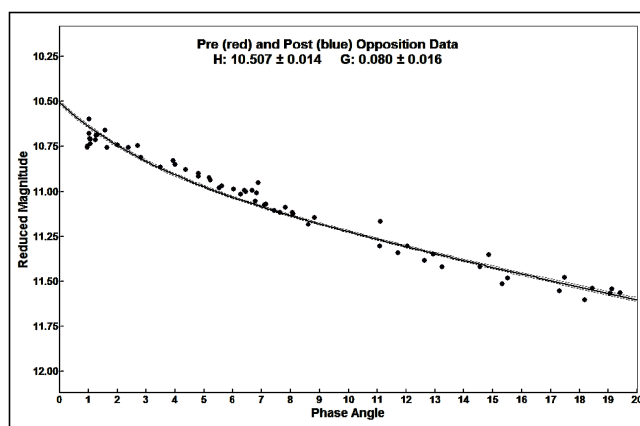


Figure 4. 1082 Pirola phase curve referenced to mean magnitude.

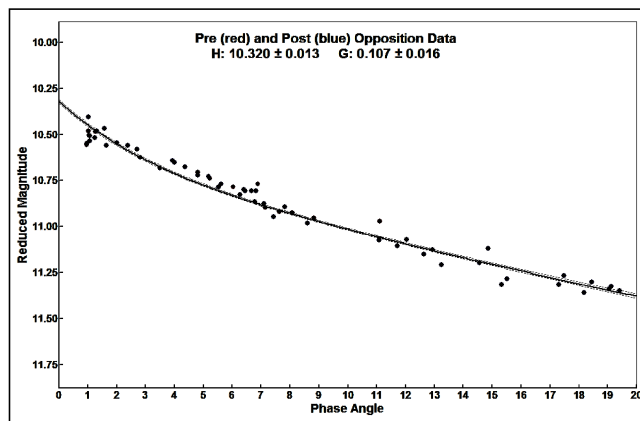


Figure 5. 1082 Pirola phase curve referenced to maximum light.

Date 2010	UT hh:mm	Observatory	Phase Angle	TS length h.h	Dpt SNR	Observed V mag	Mean mag correction	Max light correction
Oct 02	06:41	IHO	-11.11		102	14.632 ± 0.028	+0.007 (1)	-0.188 (2A)
Oct 08	05:57	IHO	-8.84	5.5	121	14.500 ± 0.022	+0.092 (1)	-0.100 (2A)
Oct 08	23:30	BAO	-8.54	6.5				
Oct 09	23:40	BAO	-8.15	6.5				
Oct 10	04:20	OMO	-8.08		118	14.680 ± 0.022	-0.113 (1)	-0.312 (2A)
Oct 10	05:27	IHO	-8.06	6.0	110	14.472 ± 0.028	+0.084 (1)	-0.106 (2A)
Oct 10	23:45	BAO	-7.75	6.0				
Oct 11	07:54	OMO	-7.62		101	14.420 ± 0.023	+0.136 (1)	-0.064 (2A)
Oct 12	11:37	OMO	-7.15		129	14.700 ± 0.022	-0.194 (1)	-0.371 (2A)
Oct 13	03:41	IHO	-6.88		104	14.518 ± 0.037	-0.132 (1)	-0.315 (2A)
Oct 15	04:14	OMO	-6.04		93	14.297 ± 0.023	+0.119 (1)	-0.082 (2A)
Oct 17	03:47	OMO	-5.22		92	14.250 ± 0.029	+0.118 (1)	-0.084 (2A)
Oct 18	03:51	OMO	-4.80		87	14.220 ± 0.027	+0.107 (1)	-0.085 (2A)
Oct 22	23:20	BAO	-2.80	6.0				
Oct 27	03:09	OMO	-1.27	8.5	123	13.927 ± 0.019	+0.200 (1)	-0.003 (2A)
Oct 28	03:02	OMO	-1.04		120	13.970 ± 0.028	+0.177 (1)	-0.024 (2A)
Oct 28	04:37	IHO	-1.03		144	14.048 ± 0.031	+0.071 (1)	-0.124 (2A)
Oct 28	20:19	BAO	-0.96	5.0	131	14.110 ± 0.040	+0.082 (1)	-0.111 (2A)
Oct 29	03:09	OMO	+0.95		117	14.013 ± 0.028	+0.188 (1)	-0.018 (2A)
Oct 29	20:05	BAO	+1.02	5.6	155	13.942 ± 0.094	+0.105 (1)	-0.089 (2A)
Oct 30	02:54	OMO	+1.07		114	13.993 ± 0.022	+0.165 (1)	-0.036 (2A)
Oct 30	04:28	IHO	+1.08		126	14.136 ± 0.039	+0.048 (1)	-0.150 (2A)
Oct 30	20:12	BAO	+1.24	5.5	89	14.108 ± 0.042	+0.058 (1)	-0.139 (2A)
Oct 31	02:56	OMO	+1.32		118	13.963 ± 0.025	+0.176 (1)	-0.029 (2A)
Oct 31	21:23	BAO	+1.56	4.0	84	14.237 ± 0.042	-0.121 (1)	-0.313 (2A)
Nov 01	02:58	OMO	+1.65	9.0	119	14.083 ± 0.016	+0.129 (1)	-0.067 (2A)
Nov 02	03:17	OMO	+2.02		119	14.093 ± 0.025	+0.112 (1)	-0.084 (2A)
Nov 03	02:46	IHO	+2.39	5.5	141	14.112 ± 0.033	+0.110 (1)	-0.085 (2A)
Nov 03	21:27	BAO	+2.70	5.5	86	14.528 ± 0.054	-0.311 (1)	-0.477 (2A)
Nov 04	03:51	OMO	+2.81		107	14.287 ± 0.020	-0.002 (1)	-0.189 (2A)
Nov 05	20:29	BAO	+3.49		104	14.563 ± 0.051	-0.216 (1)	-0.398 (2A)
Nov 06	23:24	BAO	+3.94		89	14.217 ± 0.048	+0.103 (1)	-0.087 (2A)
Nov 07	03:32	OMO	+4.01		99	14.407 ± 0.020	-0.068 (1)	-0.266 (2A)
Nov 08	01:26	IHO	+4.38		106	14.218 ± 0.029	+0.158 (1)	-0.045 (2A)
Nov 09	02:14	OMO	+4.80		93	14.373 ± 0.023	+0.049 (1)	-0.148 (2A)
Nov 10	01:31	IHO	+5.18		110	14.324 ± 0.017	+0.111 (1)	-0.085 (2A)
Nov 10	21:25	BAO	+5.53		101	14.580 ± 0.041	-0.082 (1)	-0.277 (2A)
Nov 11	02:24	OMO	+5.61		85	14.513 ± 0.024	-0.023 (1)	-0.224 (2A)
Nov 12	18:39	BAO	+6.26		102	14.660 ± 0.023	-0.111 (1)	-0.300 (2A)
Nov 13	02:24	OMO	+6.40		150	14.640 ± 0.021	-0.109 (1)	-0.305 (2A)
Nov 13	05:24	IHO	+6.44		115	14.488 ± 0.033	+0.051 (1)	-0.147 (2A)
Nov 13	18:28	BAO	+6.65		102	14.694 ± 0.051	-0.158 (1)	-0.348 (2A)
Nov 14	01:52	OMO	+6.78		102	14.640 ± 0.015	-0.044 (1)	-0.232 (2A)
Nov 14	03:40	TMO-RCT	+6.81		121	14.773 ± 0.022	-0.222 (1)	-0.421 (2A)
Nov 14	22:26	BAO	+7.11		101	14.453 ± 0.051	+0.172 (1)	-0.026 (2A)
Nov 15	19:15	BAO	+7.44		116	14.990 ± 0.051	-0.323 (1)	-0.485 (2A)
Nov 16	19:35	BAO	+7.82		81	14.831 ± 0.041	-0.172 (1)	-0.370 (2A)
Nov 18	22:19	BAO	+8.60		115	14.600 ± 0.031	+0.172 (1)	-0.029 (2A)
Nov 26	01:35	OMO	+11.09		115	15.130 ± 0.022	-0.162 (1)	-0.390 (2B)
Nov 28	01:27	OMO	+11.72		108	15.140 ± 0.022	-0.107 (1)	-0.345 (2B)
Nov 28	23:40	IHO	+12.05	7.5	88	14.848 ± 0.019	+0.158 (1)	-0.074 (2B)
Dec 01	01:31	OMO	+12.64		128	15.040 ± 0.022	+0.073 (1)	-0.164 (2B)
Dec 02	02:49	OMO	+12.95		140	14.910 ± 0.013	+0.178 (1)	-0.045 (2B)
Dec 03	03:12	OMO	+13.24		137	14.980 ± 0.022	+0.192 (1)	-0.020 (2B)
Dec 08	01:32	OMO	+14.56		118	15.060 ± 0.022	+0.179 (1)	-0.042 (2B)
Dec 09	06:48	TMO-MNT	+14.86		149	15.320 ± 0.021	-0.133 (1)	-0.368 (2B)
Dec 11	05:20	OMO	+15.32		102	15.603 ± 0.015	-0.225 (1)	-0.428 (2B)
Dec 12	01:26	OMO	+15.51		132	15.200 ± 0.022	+0.157 (1)	-0.042 (2B)
Dec 21	06:06	OMO	+17.31	5.0	119	15.400 ± 0.022	+0.159 (1)	-0.079 (2B)
Dec 22	06:59	OMO	+17.48	6.5	91	15.310 ± 0.016	+0.190 (1)	-0.023 (2B)
Dec 27	03:29	TMO-MNT	+18.18		88	15.700 ± 0.022	-0.007 (1)	-0.249 (2B)
Dec 29	03:38	TMO-MNT	+18.42		165	15.573 ± 0.021	+0.088 (1)	-0.151 (2B)
Jan 04	03:20	TMO-MNT	+19.05		65	15.600 ± 0.018	+0.177 (1)	-0.052 (2B)
Jan 05	02:34	TMO-MNT	+19.13		91	15.584 ± 0.027	+0.183 (1)	-0.037 (2B)
Jan 09	03:42	TMN-MNT	+19.41		142	15.700 ± 0.021	+0.147 (1)	-0.070 (2B)

Table I. Summary of observations. LC identifier (1) = sessions 1-17, (2A) = sessions 1-14, and (2B) = sessions 15-17.