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The pre-main-sequence star V1184 Tauri (CB 34V) at the end of prolonged eclipse★ *(Research Note)*

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ABSTRACT

Aims. V1184 Tau (CB 34V) lies in the field of the Bok globule CB 34 and was discovered as a large amplitude variable in 1993. According to the first hypothesis of the variability of the star, it is a FU Orionis candidate erupted between 1951 and 1993. During subsequent observations, the star manifests large amplitude variability interpreted as obscuration from circumstellar clouds of dust. We included V1184 Tau (CB 34V) in our target list of highly variable pre-main-sequence stars to determine the reasons for the variations in the brightness of this object.

Methods. Data from *BVRI* photometric observations of the young stellar object V1184 Tau, obtained in the period 2008−2015, are presented in the paper. These data are a continuation of our optical photometric monitoring of the star began in 2000 and continuing to date. The photometric observations of V1184 Tau were performed in two observatories with two medium-sized and two small telescopes.

Results. Our results indicate that during periods of maximum light the star shows characteristics typical of T Tauri stars. During the observed deep minimum in brightness, however, V1184 Tau is rather similar to UX Orionis objects. The deep drop in brightness began in 2003 ended in 2015 as the star has returned to maximum light. The light curve during the drop is obviously asymmetric as the decrease in brightness lasts two times longer than the rise. The observed colour reverse on the colour-magnitude diagrams is also confirmation of obscuration from circumstellar clouds of dust as a reason for the large amplitude variability in the brightness.

Key words. stars: pre-main sequence – stars: variables: T Tauri, Herbig Ae/Be – stars: individual: V1184 Tau

1. Introduction

Photometric variability is a fundamental characteristic of all types of pre-main-sequence (PMS) stars. In many cases, the discovery of variability is a proof for the membership of stars in a certain group of young objects. Depending on the mass, PMS stars are divided in two main groups: the widely distributed T Tauri stars (TTS), determined as young low-mass stars ($M \leq 2\ M_{\odot}$) with emission line spectra and irregular photometric variability; and the more massive ($M > 2\ M_{\odot}$) Herbig Ae/Be stars (HAEBE). Respectively TTS can be divided in two subgroups: classical T Tauri (CTT) stars surrounded by massive accretion circumstellar disks and weak line T Tauri (WTT) stars without indications of accretion from the disk (Bertout 1989).

In accordance with Herbst et al. (2007) the photometric variability of WTT stars is caused by the presence of large cool spots or groups of spots analogous to sunspots. The periods of variability on timescales of days and amplitudes up to $0\overset{m}{.}6$ (I) are typical of the WTT stars variability. The brightness variations of CTT stars are more complicated: the variability is produced by mixture of cool and hot surface spots with non-periodic variations and amplitudes up to 2–3 mag (I).

The very rare phenomena in PMS evolution, i.e. large amplitude, long lasting eruptions, are grouped into two main types: FU Orionis (FUor) and EX Lupi. The outburst of FUor objects usually continues over several decades, and the time of the rise of brightness is less than the time of the decline (see Audard et al. 2014; Reipurth & Aspin 2010, and references therein). Well-studied FUors have the following same characteristics: a $\Delta V \approx 4{-}6$ mag. amplitude of the outburst, connection with reflection nebulae, belonging to regions of star formation, an F-G supergiant spectrum in the optical range, a P Cyg profile of Hα line and Na I doublet, a strong LiI 6707 Å absorption line, and CO bands in near-infrared spectra (Herbig 1977).

A sizable number of HAEBE stars with spectral type later than A0 and some early F-G types TTS exhibit very strong photometric variability with abrupt quasi-Algol drops in brightness with amplitudes reaching to 3 mag. (V) (Nata et al. 1997). During the very deep minima in brightness an increasing of polarization and peculiar colour variability are observed. The prototype of this group of PMS stars named UXors is UX Orionis. The widely accepted explanation of its variability is a variable extinction from orbiting circumstellar clumps or clouds of dust or from edge-on circumstellar disks (Grinin et al. 1991).

The unique PMS star V1184 Tau (also known as CB 34V) discovered by Yun et al. (1997) is located in the field of the Bok

★ Appendix A is available in electronic form at http://www.aanda.org

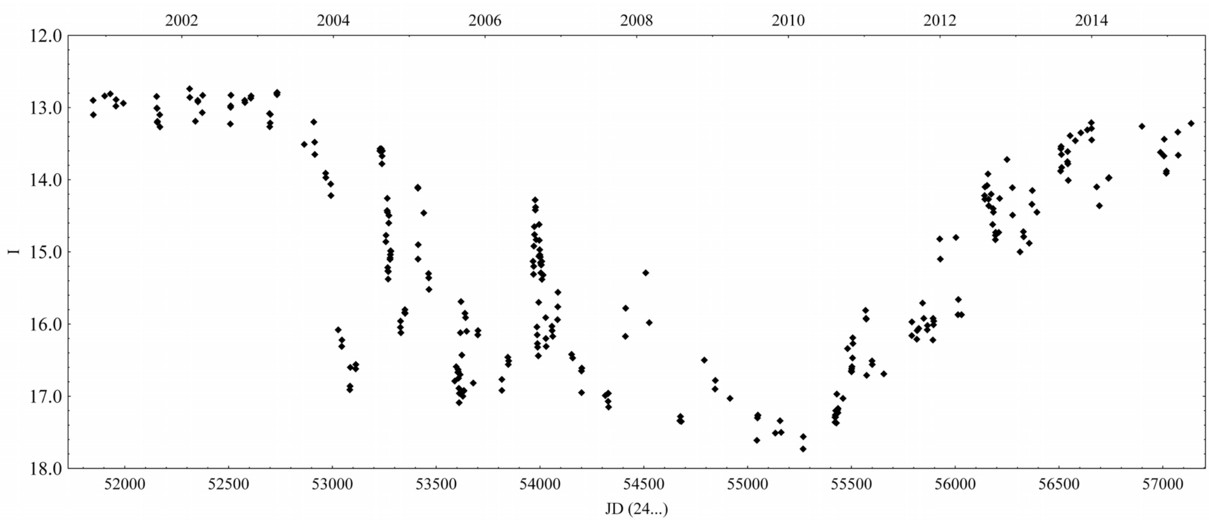

Fig. 1. *I* light curve of V1184 Tau for the period October 2000−April 2015.

globule CB 34 (Clemens & Barvainis 1988). The comparison of CCD images that Yun et al. (1997) obtained in 1993 with plates from Palomar Observatory Sky Survey obtained in 1951 reveals an increase in brightness of this star at $3\overset{m}{.}7$ (*R*). The first supposition of Yun et al. (1997) about the nature of V1184 Tau is that it exhibits a FUor type of outburst in optical wavelengths. Alves et al. (1996) defined the spectral type of V1184 Tau as G5 (III-IV), the mass of the star $\sim 2\ M_{\odot}$, and the age $\sim 10^6$ yrs. Tackett et al. (2003) discovered a 2.372 days rotation period of V1184 Tau, suggesting the presence of large cool spots on the stellar surface.

The data presented in this paper are a continuation of the optical photometric monitoring of V1184 Tau began in 2000. The photometric and spectroscopic study presented in our first paper (Semkov 2003) reveals V1184 Tau as a possible WTT star with an amplitude of $0\overset{m}{.}5$ (*I*) and spectral variability. In our second paper (Semkov 2004), the beginning of a new very deep minimum in brightness of V1184 Tau was reported. In the third paper from our study (Semkov 2006), new data from optical photometry and spectroscopy of V1184 Tau in the period during the deep minimum are reported. In Semkov et al. (2008), data from archival photographic plates are presented, which proves that an unknown minimum of brightness exists during the approximate period 1980–1985. Optical photometric data obtained at the time of our photometric monitoring have been published in Tackett et al. (2003), Barsunova et al. (2006), and Grinin et al. (2009).

2. Observations

The photometric observations of V1184 Tau were performed in two observatories with four telescopes: the 2-m Ritchey-Chrétien-Coudé, the 50/70-cm Schmidt and 60-cm Cassegrain telescopes of the Rozhen National Astronomical Observatory (Bulgaria), and the 1.3-m Ritchey-Chrétien telescope of the Skinakas Observatory[1] of the University of Crete (Greece).

The observations were performed with five types of CCD cameras: Vers Array 1300B at the 2-m RCC telescope, ANDOR DZ436-BV at the 1.3-m RC telescope, SBIG STL-11000M and FLI PL16803 at the 50/70-cm Schmidt telescope, and FLI PL9000 at the 60-cm Cassegrain telescope. The technical parameters for the CCD cameras used, observational procedure, and data reduction process are described in Ibryamov et al. (2015). All frames were taken through a standard Johnson-Cousins set of filters. To minimize the light from the surrounding nebula all data were analysed using the same aperture, which was chosen as 4″ radius. The background is taken from 15″ to 20″. As a reference the *IRVB* comparison sequence reported in Semkov (2003, 2006) was used.

[1] Skinakas Observatory is a collaborative project of the University of Crete, the Foundation for Research and Technology, Greece, and the Max-Planck-Institut für Extraterrestrische Physik, Germany.

3. Results and discussion

The new data from our optical photometric observations of V1184 Tau are presented in Table A.1. The columns contains the date and Julian date (J.D.) of observation, *IRVB* magnitudes of V1184 Tau, the telescope and CCD camera used. The mean values of instrumental errors of our photometric study are listed in Semkov et al. (2008). In very deep minimums the star can be observed only in *V*, *R*, and *I* bands with the middle size telescopes (2-m RCC and 1.3-m RC) and only in *R* and *I* bands with the small telescopes (50/70-cm Schmidt and 60-cm Cassegrain). The *I* light curve of V1184 Tau from all our observations is shown in Fig. 1. The error bars are not shown in the figure, as their size is comparable to the symbols used.

The data collected during our long-term photometric monitoring suggest that from October 2000 to April 2003 the brightness of V1184 Tau varies with an amplitude of about $0\overset{m}{.}5$ (*I*) without increasing or decreasing. Since August 2003 a gradual decrease in brightness has begun and the magnitude of the star decreased with $\sim 4^{m}$ (*I*) until March 2004. Over the next six years, the brightness of the star changed rapidly, and several rises and drops with amplitudes of several magnitudes are observed. The minimum brightness of V1184 Tau ($I = 17\overset{m}{.}73$) was registered in March 2010. Therefore, the process of decrease in brightness continues nearly seven years.

Since the summer of 2010 the brightness of the star began to rise gradually until the spring of 2015 when it reached values close to the maximum light. Process of increasing in brightness is relatively fast and with a relatively smaller brightness variations, unlike the process of decreasing in brightness. Therefore, the deep minimum in brightness of V1184 Tau lasts around 12 years and the registered amplitude is $\Delta I \approx 4\overset{m}{.}8$.

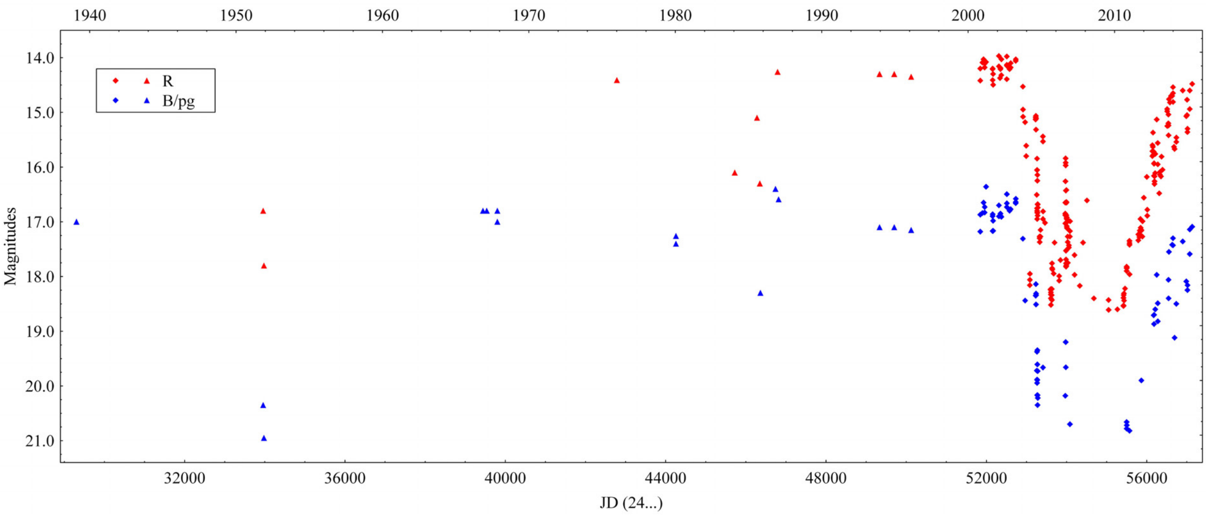

Fig. 2. Historical R and B/pg light curves of V1184 Tau.

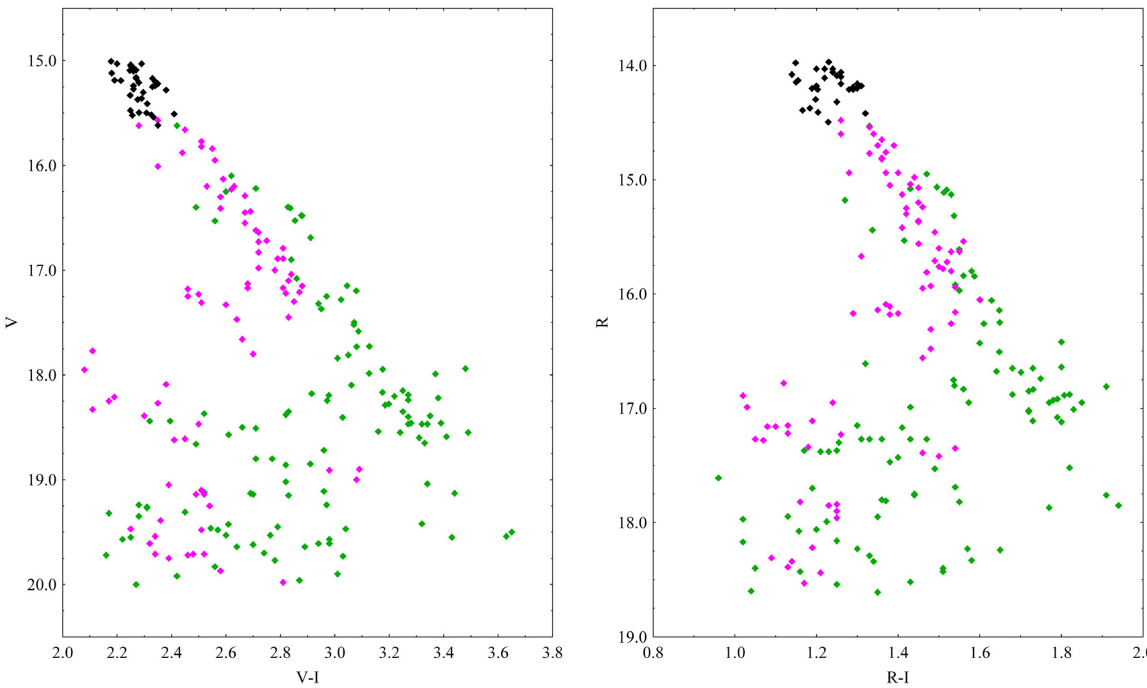

Fig. 3. $V/V-I$ and $R/R-I$ diagrams for the period of our photometric observations. In the figure, the black diamonds denote observations from October 2000 to April 2003 (maximum level of brightness out of obscuration), the green diamonds observations from August 2003 to March 2010 (when the brightness of the star dropped) and the pink diamonds from August 2010 to April 2015 (when the brightness of the star increased).

Figure 2 shows the long-term B/pg and R light curves of V1184 Tau from all available observations. The diamonds denote our CCD photometric data; triangles denote the photographic data collected from archives of several telescopes (Semkov et al. 2008). The figure shows that a total of three deep minimum in brightness have been registered to date: the first around 1951, the second between 1976 to 1985, and the last from 2003 to 2015. Duration of the first minimum documented on the photographic plates from Palomar Observatory Sky Survey is still undetermined, while the duration of the second minimum ranges between six and nine years. Detailed photometric study of the third minimum indicates a complex asymmetrical light curve, which is evidence of the irregular structure of the eclipsing object.

The multi-colour photometry obtained during the deep minimum allows us to examine the variation of colour indices with stellar brightness. In Fig. 3 we plot the measured colour indices $V-I$ versus V and $R-I$ versus R stellar magnitude. The results from our study indicate that the star is not obscured by a compact object, but rather from large and dense clouds of dust. Also, our data indicate that the star has been relatively redder during the decrease in brightness than during the rise in brightness.

During the maximum light the colour variability (star becomes redder as it fades) is typical for WTT stars with large cool spots. This variability is caused by the rotation of the spotted surface. During the beginning of the eclipse the star also becomes redder, when its light is covered by dust clouds on the line of seeing. In this case, we assume that the reddening of the star is caused by the variable extinction from the circumstellar environment. However, from a certain magnitude called turning point (in this case $V \sim 18$ mag) the colour of the star becomes bluer. The reason for this change is that the obscuration rise vastly and the part of the scattered light in the total observed light from the star is significant.

This effect of colour reversal (so-called "blueing") was described in many papers (Bibo & The 1990; Grinin et al. 1994). In accordance with the model of dust clumps obscuration, the observed colour reversal is produced by the scattered light from the small dust grains. Our photometric data confirm the existence of a blueing effect in the colour/magnitude diagrams of V1184 Tau, a typical feature of the PMS stars from UXor type. This is independent evidence that the variability of V1184 Tau is dominated by the variable extinction from circumstellar environment. Meanwhile, large cool spots should continue to form on the stellar surface, which additionally modify the brightness and the colour of the star. Therefore, we observe a combination of both types of variability, which contributes to the large deviation of the points on the colour/magnitude diagrams. The main cause of the observed large deviation of the points, however, should be the strong fluctuations of the scattered light during our long-term photometric monitoring of the extinction event.

Based on data from infrared *JHK* photometry, Grinin et al. (2009) propose that the increase in extinction and the drop in star's brightness can be induced by enhanced accretion from the circumstellar disks. The lack of a fall in the *K* band is explained by a disk model with a puffed up inner rim, whose effective width is increased as a result of enhanced accretion rate. The presence of another reason for stellar variability, i.e. episodic accretion, may also increase the dispersion of points in the $V/V-I$ and $R/R-I$ diagrams.

The results from our 15 years of photometric monitoring show that V1184 Tau has no analogue among the PMS variables. A similar amplitude and duration of the decrease in brightness was only observed in the case of CQ Tau (Grinin et al. 2008). Unlike V1184 Tau, which is WTT star, CQ Tau is a typical HAEBE star with a bigger mass and from an earlier spectral type. The observed decrease in brightness during the period 2003–2015 lasted somewhat longer than our prediction (Semkov et al. 2008), which still does not exclude the presence of the periodicity. The extremely large amplitude, rapid variability in brightness and significant deviation of colour indices can only be explained by the presence of several variability mechanisms, with variable extinction the dominant mechanism.

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Appendix A

Table A.1. Photometric CCD observations of V1184 Tau during the period February 2008–April 2015.

Date	JD (24...)	*I*	*R*	*V*	*B*	Telescope	CCD
12.02.2008	54 509.332	15.29	16.61	–	–	Scm	ST11000
29.02.2008	54 526.397	15.98	–	–	–	Scm	ST11000
26.07.2008	54 673.602	17.34	–	–	–	1.3 m	ANDOR
29.07.2008	54 676.605	17.28	–	–	–	1.3 m	ANDOR
02.08.2008	54 680.595	17.35	18.40	19.57	–	1.3 m	ANDOR
20.11.2008	54 791.491	16.50	–	–	–	Scm	ST11000
11.01.2009	54 843.237	16.90	–	–	–	Scm	ST11000
12.01.2009	54 844.310	16.78	–	–	–	Scm	ST11000
24.03.2009	54 915.303	17.03	–	–	–	Scm	ST11000
01.08.2009	55 044.604	17.61	–	–	–	1.3 m	ANDOR
04.08.2009	55 047.604	17.30	–	19.55	–	1.3 m	ANDOR
05.08.2009	55 048.607	17.27	18.43	19.83	–	1.3 m	ANDOR
06.08.2009	55 049.589	17.26	18.61	–	–	1.3 m	ANDOR
28.10.2009	55 133.481	17.51	–	–	–	Scm	FLI
20.11.2009	55 156.495	17.34	–	–	–	Scm	FLI
26.11.2009	55 161.520	17.50	–	19.92	–	2 m	VA
11.03.2010	55 267.299	17.73	–	20.00	–	2 m	VA
12.03.2010	55 268.269	17.56	18.60	19.72	–	2 m	VA
12.08.2010	55 420.600	17.29	18.54	19.87	–	1.3 m	ANDOR
13.08.2010	55 421.603	17.36	18.53	19.75	–	1.3 m	ANDOR
14.08.2010	55 422.603	17.26	18.39	19.72	–	1.3 m	ANDOR
15.08.2010	55 423.616	17.29	–	19.61	–	1.3 m	ANDOR
16.08.2010	55 424.610	17.20	18.34	19.54	–	1.3 m	ANDOR
19.08.2010	55 427.617	17.37	–	19.71	–	1.3 m	ANDOR
21.08.2010	55 429.607	16.97	–	19.48	–	1.3 m	ANDOR
24.08.2010	55 432.559	17.22	18.31	19.47	–	1.3 m	ANDOR
25.08.2010	55 433.576	17.19	–	19.71	–	1.3 m	ANDOR
26.08.2010	55 434.564	17.23	18.44	19.71	–	1.3 m	ANDOR
27.08.2010	55 435.575	17.17	–	19.98	–	1.3 m	ANDOR
20.09.2010	55 459.595	17.03	18.22	19.39	–	1.3 m	ANDOR
12.10.2010	55 481.545	16.34	–	–	–	1.3 m	ANDOR
29.10.2010	55 499.471	16.65	17.90	19.14	–	2 m	VA
31.10.2010	55 500.536	16.66	17.82	19.05	20.66	2 m	VA
31.10.2010	55 501.406	16.62	17.85	19.14	20.78	2 m	VA
01.11.2010	55 502.499	16.59	17.84	19.10	20.72	2 m	VA
04.11.2010	55 505.493	16.47	–	–	–	Scm	FLI
05.11.2010	55 506.484	16.19	–	–	–	Scm	FLI
07.11.2010	55 507.530	16.27	–	–	–	Scm	FLI
06.01.2011	55 568.453	15.81	17.35	18.90	–	2 m	VA
08.01.2011	55 570.298	15.92	17.42	19.00	20.82	2 m	VA
10.01.2011	55 571.510	15.93	17.39	18.91	–	2 m	VA
11.01.2011	55 573.304	16.71	17.96	19.25	–	2 m	VA
06.02.2011	55 599.347	16.51	–	–	–	Sch	FLI
07.02.2011	55 600.358	16.56	–	–	–	Sch	FLI
04.04.2011	55 656.278	16.69	–	–	–	Sch	FLI
17.08.2011	55 790.591	16.16	17.34	18.61	–	1.3 m	ANDOR
18.08.2011	55 791.607	15.97	17.23	18.47	–	1.3 m	ANDOR
10.09.2011	55 815.494	16.21	17.28	18.62	–	1.3 m	ANDOR
12.09.2011	55 816.565	16.09	17.22	18.39	–	1.3 m	ANDOR
20.09.2011	55 824.507	16.06	17.16	–	–	1.3 m	ANDOR
07.10.2011	55 842.462	15.71	16.95	18.09	–	1.3 m	ANDOR
13.10.2011	55 848.460	15.92	17.11	18.27	–	1.3 m	ANDOR
30.10.2011	55 865.463	16.08	17.16	18.25	–	2 m	VA
31.10.2011	55 866.468	16.02	17.15	18.21	19.90	2 m	VA
26.11.2011	55 892.430	16.22	17.27	18.33	–	2 m	VA
27.11.2011	55 893.387	15.92	–	–	–	Sch	FLI
29.11.2011	55 895.456	16.01	–	–	–	Sch	FLI
30.11.2011	55 896.422	15.96	16.99	–	–	Sch	FLI
30.12.2011	55 925.532	14.82	–	–	–	Sch	FLI
01.01.2012	55 928.327	15.10	16.56	17.80	–	Sch	FLI
16.03.2012	56 003.320	14.80	16.18	17.31	–	Sch	FLI
26.03.2012	56 013.322	15.87	16.89	17.95	–	2 m	VA
28.03.2012	56 015.326	15.66	16.78	17.77	–	2 m	VA
12.04.2012	56 030.279	15.87	–	–	–	Sch	FLI

Table A.1. continued.

Date	JD (24...)	*I*	*R*	*V*	*B*	Telescope	CCD
02.08.2012	56 141.602	14.22	15.71	17.00	–	1.3 m	ANDOR
03.08.2012	56 142.603	14.27	15.80	17.15	–	1.3 m	ANDOR
04.08.2012	56 143.602	14.10	15.60	16.89	–	1.3 m	ANDOR
14.08.2012	56 153.608	14.08	15.63	16.89	–	1.3 m	ANDOR
18.08.2012	56 157.622	13.92	15.37	16.64	–	1.3 m	ANDOR
21.08.2012	56 160.572	14.27	15.78	17.10	–	1.3 m	ANDOR
22.08.2012	56 161.598	14.36	–	–	–	Sch	FLI
03.09.2012	56 173.549	14.20	15.72	17.04	18.71	1.3 m	ANDOR
10.09.2012	56 180.591	14.62	16.16	17.45	–	1.3 m	ANDOR
11.09.2012	56 182.500	14.40	15.94	17.22	18.87	1.3 m	ANDOR
13.09.2012	56 183.541	14.45	15,93	17.13	18.70	1.3 m	ANDOR
23.09.2012	56 193.542	14.83	16.31	17.47	–	1.3 m	ANDOR
23.09.2012	56 193.559	14.77	16.17	–	–	Sch	FLI
24.09.2012	56 194.531	14.73	16.26	17.33	–	Sch	FLI
09.10.2012	56 209.547	14.73	16.11	17.23	–	Sch	FLI
13.10.2012	56 214.396	14.26	15.76	16.98	18.60	2 m	VA
17.11.2012	56 249.430	13.72	15.13	16.30	17.97	Sch	FLI
14.12.2012	56 275.562	14.11	15.56	16.83	18.49	2 m	VA
14.12.2012	56 276.414	14.49	15.95	17.17	18.82	2 m	VA
19.01.2013	56 312.357	15.00	16.48	17.66	–	2 m	VA
04.02.2013	56 328.438	14.72	16.09	17.18	–	Sch	FLI
05.02.2013	56 329.422	14.79	16.14	17.25	–	Sch	FLI
04.03.2013	56 356.373	14.88	16.17	–	–	60 cm	FLI
17.03.2013	56 369.341	14.34	15.81	17.21	–	2 m	VA
19.03.2013	56 371.332	14.15	–	–	–	2 m	VA
10.04.2013	56 393.277	14.45	16.05	17.30	–	Sch	FLI
03.08.2013	56 507.572	13.88	–	–	–	2 m	VA
04.08.2013	56 508.573	13.57	14.94	16.20	–	2 m	VA
05.08.2013	56 509.575	13.54	14.98	–	–	Sch	FLI
06.08.2013	56 510.573	13.54	14.94	16.13	–	Sch	FLI
07.08.2013	56 511.574	13.65	–	–	–	Sch	FLI
08.08.2012	56 512.571	13.83	15.25	16.41	–	Sch	FLI
05.09.2013	56 540.564	13.75	15.20	16.44	–	Sch	FLI
06.09.2013	56 541.546	13.61	15.04	16.23	–	Sch	FLI
07.09.2013	56 542.537	13.78	15.24	16.45	18.06	Sch	FLI
09.09.2013	56 544.528	14.01	15.42	16.73	18.40	2 m	VA
17.09.2013	56 553.525	13.39	14.76	15.95	17.55	1.3 m	ANDOR
13.10.2013	56 578.592	13.46	14.82	–	–	60 cm	FLI
08.11.2013	56 604.545	13.35	14.70	–	–	60 cm	FLI
09.12.2013	56 636.332	13.31	14.70	15.82	17.42	2 m	VA
28.12.2013	56 655.432	13.21	14.54	15.66	17.30	Sch	FLI
30.12.2013	56 656.517	13.29	14.65	15.84	17.43	Sch	FLI
30.12.2013	56 657.279	13.45	14.81	–	–	Sch	FLI
23.01.2014	56 681.461	14.10	15.63	16.89	–	Sch	FLI
05.02.2014	56 694.412	14.36	15.67	17.17	19.12	2 m	VA
21.03.2014	56 738.291	13.98	15.54	16.79	18.50	Sch	FLI
23.03.2014	56 740.302	13.97	15.46	16.72	–	Sch	FLI
30.08.2014	56 899.529	13.26	14.60	15.77	17.36	1.3 m	ANDOR
26.11.2014	56 988.337	13.62	15.07	16.29	18.09	Sch	FLI
14.12.2014	57 005.532	13.67	15.05	16.20	–	Sch	FLI
15.12.2014	57 006.576	13.44	14.77	15.88	–	Sch	FLI
25.12.2014	57 016.556	13.91	15.36	16.62	18.25	2 m	VA
25.12.2014	57 017.346	13.88	15.30	16.55	18.16	2 m	VA
18.02.2015	57 072.365	13.34	14.60	15.62	17.14	Sch	FLI
20.02.2015	57 074.361	13.66	14.94	16.01	17.59	Sch	FLI
23.04.2015	57 136.255	13.22	14.48	15.57	17.09	Sch	FLI