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# Photometry of Centaurs and trans-Neptunian objects: 2060 Chiron (1977 UB), 10199 Chariklo ( 1997 CU $_{26}$ ), 38628 Huya (2000 EB 173 ), 28978 Ixion ( $2001 \mathrm{KX}_{76}$ ), and 90482 Orcus (2004 DW) 

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#### Abstract

Both Centaurs and trans-Neptunian objects (TNOs) are minor bodies found in the outer Solar System. Centaurs are a transient population that moves between the orbits of Jupiter and Neptune, and they probably diffused out of the TNOs. TNOs move mainly beyond Neptune. Some of these objects display episodic cometary behaviour; a few percent of them are known to host binary companions. Here, we study the lightcurves of two Centaurs - 2060 Chiron (1977 UB) and 10199 Chariklo ( $1997 \mathrm{CU}_{26}$ ) - and three TNOs — 38628 Huya (2000 EB ${ }_{173}$ ), 28978 Ixion (2001 $\mathrm{KX}_{76}$ ), and 90482 Orcus ( 2004 DW) - and the colours of the Centaurs and Huya. Precise, $\sim 1 \%, R$-band absolute CCD photometry of these minor bodies acquired between 2006 and 2011 is presented; the new data are used to investigate the rotation rate of these objects. The colours of the Centaurs and Huya are determined using $B V R I$ photometry. The point spread function of the five minor bodies is analysed, searching for signs of a coma or close companions. Astrometry is also discussed. A


[^0]periodogram analysis of the light-curves of these objects gives the following rotational periods: $5.5 \pm 0.4 \mathrm{~h}$ for Chiron, $7.0 \pm 0.6 \mathrm{~h}$ for Chariklo, $4.45 \pm 0.07 \mathrm{~h}$ for Huya, $12.4 \pm 0.3 \mathrm{~h}$ for Ixion, and $11.9 \pm 0.5 \mathrm{~h}$ for Orcus. The colour indices of Chiron are found to be $B-V=0.53 \pm 0.05, V-R=0.37 \pm 0.08$, and $R-I=$ $0.36 \pm 0.15$. The values computed for Chariklo are $V-R=0.62 \pm 0.07$ and $R-I=0.61 \pm 0.07$. For Huya, we find $V-R=0.58 \pm 0.09$ and $R-I=0.64 \pm 0.20$. Our rotation periods are similar to and our colour values are consistent with those already published for these objects. We find very low levels of cometary activity (if any) and no sign of close or wide binary companions for these minor bodies.

Keywords Minor planets, asteroids: individual: 2060 Chiron (1977 UB) • Minor planets, asteroids: individual: 10199 Chariklo ( $1997 \mathrm{CU}_{26}$ ) • Minor planets, asteroids: individual: 38628 Huya ( $2000 \mathrm{~EB}_{173}$ ) • Minor planets, asteroids: individual: 28978 Ixion (2001 $\mathrm{KX}_{76}$ ) • Minor planets, asteroids: individual: 90482 Orcus (2004 DW) • Techniques: photometric

## 1 Introduction

Centaurs are a group of minor planets found in the outer Solar System whose orbits are strongly perturbed as a result of crossing the paths of one or more of the giant planets (Di Sisto \& Brunini 2007; Galiazzo et al. 2015). Objects in this dynamical class are widely thought to be former members of the so-called TransNeptunian Belt (TNB; e.g. Jewitt \& Luu 1993) or even the Oort Cloud (Levison et al. 2001), and some of them may be transitioning to become short-period comets (e.g. Levison \& Duncan 1997). However, the possible existence of trans-Plutonian planets (see e.g. Trujillo \& Sheppard 2014; de la Fuente Marcos \& de la Fuente

Marcos 2014; de la Fuente Marcos et al. 2015; Batygin \& Brown 2016) may affect the dynamical pathways leading to this dynamical class. This transient population features perihelia of less than 30 AU , but outside the orbit of Jupiter. A number of them display episodic cometary behaviour (e.g. Jewitt 2009). TransNeptunian objects (TNOs) inhabit the TNB and their semi-major axes lie beyond that of Neptune. TNOs actively engaged in mean-motion resonances with Neptune are believed to have become trapped there during planet migration, late in the giant-planet formation process (e.g. Gladman et al. 2012). Issues of nomenclature in the outer Solar System are discussed by e.g. Gladman et al. (2008). A few percent of both Centaurs and TNOs are known to host binary companions (e.g. Walsh 2009; Naoz et al. 2010; Parker 2011; Parker et al. 2011).

In this paper, we present new photometric data of two Centaurs - 2060 Chiron (1977 UB) and 10199 Chariklo (1997 CU 26 ) - and three TNOs - 38628 Huya (2000 EB ${ }_{173}$ ), 28978 Ixion ( $2001 \mathrm{KX}_{76}$ ), and 90482 Orcus (2004 DW). The observations are part of a programme focused on the study of Centaurs, TNOs, and their possible cometary activity. Observations and data processing techniques are described in Sect. 2. Chiron is revisited in Sect. 3. New data and results for Chariklo are presented in Sect. 4. Those for TNOs Huya, Ixion, and Orcus are given in Sects. 5-7, respectively. Results are discussed and conclusions summarised in Sect. 8.

## 2 Observations and data reduction

The observations presented here were acquired at the Las Campanas Observatory, between 2006 and 2011, using the $1.0-\mathrm{m}$ Swope telescope equipped with the site\#3 $2048 \times 3150$ CCD camera. In the frames, the field of view is about $14.8 \times 22.8$ and the pixel scale is $0.435^{\prime \prime}$ /pixel. Preliminary processing of the CCD frames was carried out using standard routines of the IRAF package 1 Both dome and sky flat-field frames were obtained in each filter $(B V R I)$ as needed and the images were also corrected for non-linearity (Hamuy et al. 2006; Carraro 2009); additional details can be found in Galiazzo (2009). Photometric calibration of the targets including appropriate zero points and color terms computed for the individual observing nights - when

[^1]photometric - was performed. As an example, the following relationships between the instrumental (lowercase letters) and the standard colours and magnitudes were adopted in the case of Chariklo (see Sect. 4):
\[

$$
\begin{align*}
V= & 22.115(0.004)+v-0.068(0.007) \times(B-V) \\
& +0.16(0.02) \times X  \tag{1}\\
B= & 22.084(0.004)+b+0.054(0.007) \times(B-V) \\
& +0.30(0.02) \times X  \tag{2}\\
I= & 22.179(0.006)+i+0.058(0.009) \times(V-I) \\
& +0.06(0.02) \times X \tag{3}
\end{align*}
$$
\]

where $X$ is the airmass and the values of the errors associated with the various coefficients appear in parentheses. These expressions were derived merging together standard stars from three different photometric nights after checking that their apparent brightnesses were stable. Second order color terms were computed, but turned out to be negligible. Astrometric calibration of the CCD frames was performed using the algorithms of the Astrometry.net system (Lang et al. 2010). In the data tables presented here, when no magnitude is provided for a given astrometric entry (see Appendix A), it means that it was not computed because of the low quality of the CCD frame or the presence of stars too close (even partially or completely blended with it) to the photometric target. Due to the sparse nature of our data, period determination is made using one of the string-length period search algorithms, the LaflerKinman method (Lafler \& Kinman 1965; Clarke 2002). String-length methods are better suited for this task when only a small number of randomly spaced observations are available (e.g. Dworetsky 1983). False alarm probabilities are evaluated using the Bootstrap method (e.g. Press et al. 2007) with 500 trials.

## 32060 Chiron (1977 UB)

Discovered in 1977, Chiron is the first known Centaur and one of the largest; its diameter amounts to $218 \pm 20 \mathrm{~km}$, with an albedo of $16 \pm 3 \%$ (Fornasier et al. 2013). The rotational period of Chiron as determined by Bus et al. (1989), Marcialis \& Buratti (1993) or Sheppard et al. (2008) amounts to 5.9178 h, but Fornasier et al. (2013) have found a value of $5.40 \pm 0.03 \mathrm{~h}$ in December 2011, with an amplitude equal to 0.060.07 mag. This Centaur shows cometary activity (e.g. Luu \& Jewitt 1990) and it may have a ring (Ortiz et al. 2015; Ruprecht et al. 2015). Because of this cometary activity, its absolute magnitude changes over time (Belskaya et al. 2010). BVRI photometry of Chiron was
obtained in 2006 June and again in 2011 July-August (but only in $R$ ) using the same equipment.

During the first observing run (2006 June 26 to 30), Chiron was in Capricornus; as the object's apparent sky motion during the observations was $0.11^{\prime \prime}$ /minute and the exposure time was 400 s , the expected shift during one exposure was well within the seeing disk ( $1^{\prime \prime} 20$ ). The average geocentric distance of Chiron during the observing run was $\bar{\Delta}=13.32 \mathrm{AU}$, the average heliocentric distance was $\bar{r}=14.18 \mathrm{AU}$, and the average phase angle (Earth-Chiron-Sun angle) was $\bar{\alpha}=2.3$. Table 1 includes the values of the apparent magnitude (Mag) and its associated error $( \pm \sigma)$ at the appropriate UTtime (Julian date), the filter used, the airmass (A.M.) and the solar phase angle $\alpha$ in degrees; the associated astrometry is in Table 9 In this and subsequent calculations the errors quoted correspond to one standard deviation $(1 \sigma)$ computed applying the usual expressions (see e.g. Wall \& Jenkins 2012). A total of 25 frames obtained in $R$ and one in each of the $B, V, R$, and $I$ filters are presented in Table 1.

The periodogram corresponding to the first run is shown in Fig. 11 middle panel. Our best fitting gives a rotational period $P=5.5 \pm 0.4 \mathrm{~h}$ (or a frequency of $0.183 \pm 0.014$ rotations per hour). The values of the false alarm probabilities are relatively low: the probability that there is no period with value $P$ is $1.6 \pm 0.6 \%$ and that of the observations containing a period that is different from $P$ is $<0.01 \%$. The light-curve of Chiron in Fig. 11 bottom panel, shows the detrended data (by fitting a linear function to the data and subtracting) from the top panel phased with the best-fit period, its amplitude is $\sim 0.1 \mathrm{mag}$. Its light-curve amplitude was found to be 0.088 mag in 1986 and 1988 (Bus et al. 1989) and 0.044 mag in 1991 (Marcialis \& Buratti 1993), but it was measured at $0.003 \pm 0.015 \mathrm{mag}$ with data obtained in 2013 (Ortiz et al. 2015). The raw data in Fig. 1 show a dimming trend that amounts to about 0.1 mag. Raw lightcurves often exhibit smooth trends with timescales of a few days. In our case (see also Figs. 2and 3), the smooth component seems to be roughly piecewise linear. There are multiple reasons for this behaviour, including seeing-induced variability. It may also be intrinsic to the object under study. For example, fig. 6(a) in Luu \& Jewitt (1990) shows Chiron's rotational variations superposed on a linear brightening trend and this could not be attributed to errors in the correction for atmospheric extinction; Chiron naturally exhibits short-term brightness variations (on timescales of hours). Luu \& Jewitt (1990) removed the linear trend in their fig. 6(b) to facilitate their subsequent rotational period analysis; the brightening trend amounted to about 0.12 mag which is consistent with our Fig. 1,
although in our case we observe dimming not brightening.

Unfortunately, our sparse curve does not sample the entire rotational period well and this may explain why our value of $P$ is somewhat smaller than the ones measured by other authors (i.e. Sheppard et al. 2008), although the accepted value is nearly within $1 \sigma$. However, it matches well the recent determination in Fornasier et al. (2013); the value of our amplitude is also consistent with theirs. The value of the absolute magnitude in $V$ derived by Fornasier et al. (2013) is $5.80 \pm 0.04 \mathrm{mag}$; ours is $5.75 \pm 0.06 \mathrm{mag}$ which again is compatible with theirs and also with the mean value found over 2004-2008 (see fig. 2 in Fornasier et al. 2013). The absolute magnitude in $V$ has been computed using eqs. (1) and (2) in Romanishin \& Tegler (2005).

Our photometric data are compatible with a negligible level of cometary activity at the time of the observations and we found no evidence for a comoving (close or wide) companion (see Sect. 8 for additional details). Regarding the colours of this object, we only used consecutive images, or almost consecutive, on the BVRI filters. Adopting this approach we avoid errors induced by possible rotational variability associated with surface features. The colour indices of Chiron were found to be $B-V=0.53 \pm 0.05, V-R=0.37 \pm 0.08$, and $R-I=0.36 \pm 0.15$. Our values are consistent with those already published for this object (e.g. Hainaut \& Delsanti 2002; Barucci et al. 2005).

Chiron was reobserved from 2011 July 30 to August 6 (see Tables 2 and 10). The average geocentric distance of Chiron during this second observing run was $\bar{\Delta}=15.92$ AU, the average heliocentric distance was $\bar{r}=16.84 \mathrm{AU}$, and the average phase angle was $\bar{\alpha}=1.5$. Unfortunately, the nights were not photometric and the seeing was variable and worse than that of the first run. Apparent magnitudes in Table 2 are relative to two suitable reference field stars (not known variables) close to the target body. An additional, exploratory observing run for Chiron was carried out with the Cerro Tololo InterAmerican Observatory SMARTS 1-m telescope and Y4kCam on 2006 May 19 to 22 (see Table 11). During this initial observing run only astrometry was obtained. The average geocentric distance of Chiron was $\bar{\Delta}=13.74 \mathrm{AU}$, the average heliocentric distance was $\bar{r}=14.11 \mathrm{AU}$, and the average phase angle was $\bar{\alpha}=3.9$.

## 410199 Chariklo (1997 CU 26 )

Currently the largest confirmed Centaur, Chariklo has a rotational period of $7.00 \pm 0.04 \mathrm{~h}$, an effective radius

Table 1 Photometry of 2060 Chiron (1977 UB); 2006 June. This table includes the values of the apparent magnitude (Mag) and its associated error $( \pm \sigma)$ at the appropriate UTtime (Julian date), the filter used, the airmass (A.M.) and the solar phase angle $\alpha$ in degrees.

| Julian date | Filter | A.M. | Exp. (s) | Mag | $\alpha\left(^{\circ}\right)$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 2453912.805822 | $R$ | 1.05 | 400 | $16.921 \pm 0.023$ | 2.36 |
| 2453912.824410 | $R$ | 1.07 | 400 | $16.932 \pm 0.026$ | 2.36 |
| 2453912.857975 | $R$ | 1.13 | 400 | $16.936 \pm 0.035$ | 2.35 |
| 2453912.864005 | $R$ | 1.15 | 400 | $16.924 \pm 0.024$ | 2.35 |
| 2453912.870023 | $R$ | 1.16 | 400 | $16.908 \pm 0.032$ | 2.35 |
| 2453912.876053 | $R$ | 1.19 | 400 | $16.954 \pm 0.022$ | 2.35 |
| 2453912.882083 | $R$ | 1.21 | 400 | $16.935 \pm 0.021$ | 2.35 |
| 2453912.897037 | $R$ | 1.28 | 400 | $16.981 \pm 0.021$ | 2.35 |
| 2453912.903067 | $R$ | 1.31 | 400 | $16.996 \pm 0.021$ | 2.35 |
| 2453914.689248 | $R$ | 1.28 | 400 | $17.014 \pm 0.017$ | 2.25 |
| 2453914.695278 | $R$ | 1.25 | 400 | $17.065 \pm 0.019$ | 2.25 |
| 2453914.701296 | $R$ | 1.22 | 400 | $17.091 \pm 0.021$ | 2.25 |
| 2453914.724491 | $R$ | 1.14 | 400 | $17.066 \pm 0.014$ | 2.25 |
| 2453914.730521 | $R$ | 1.13 | 400 | $17.046 \pm 0.014$ | 2.25 |
| 2453914.736539 | $R$ | 1.11 | 400 | $17.074 \pm 0.011$ | 2.25 |
| 2453914.758970 | $R$ | 1.07 | 400 | $17.061 \pm 0.012$ | 2.24 |
| 2453914.765000 | $R$ | 1.07 | 400 | $17.070 \pm 0.038$ | 2.24 |
| 2453914.771030 | $R$ | 1.06 | 400 | $17.030 \pm 0.017$ | 2.24 |
| 2453914.777049 | $R$ | 1.06 | 400 | $17.040 \pm 0.017$ | 2.24 |
| 2453914.783079 | $R$ | 1.05 | 400 | $17.032 \pm 0.018$ | 2.24 |
| 2453914.789167 | $R$ | 1.05 | 400 | $17.035 \pm 0.021$ | 2.24 |
| 2453914.794502 | $R$ | 1.05 | 400 | $17.012 \pm 0.013$ | 2.24 |
| 2453914.801227 | $R$ | 1.05 | 400 | $17.008 \pm 0.027$ | 2.24 |
| 2453914.807245 | $R$ | 1.06 | 400 | $17.076 \pm 0.059$ | 2.24 |
| 2453914.813275 | $R$ | 1.06 | 400 | $17.117 \pm 0.025$ | 2.24 |
| 2453912.798391 | $B$ | 1.05 | 600 | $17.815 \pm 0.025$ | 2.36 |
| 2453912.811991 | $V$ | 1.06 | 400 | $17.287 \pm 0.026$ | 2.36 |
| 2453912.818206 | $I$ | 1.06 | 400 | $16.564 \pm 0.590$ | 2.36 |
|  |  |  |  |  |  |



Fig. 1 Chiron: 2006 June 26-30 run. $R$-band data, raw (red) and detrended (black), but uncorrected for rotational variation, used to compute the rotation period of Chiron (top panel). Lafler-Kinman periodogram of Chiron (middle panel) using $4 \times 25$ test frequencies. Periods yielding the lowest normalized power are the most likely, statistically speaking. The lowest value corresponds to a rotation period of $5.5 \pm 0.4 \mathrm{~h}$ or a frequency of $0.183 \pm 0.014$ cycles $/ \mathrm{h}$ with a false alarm probability ( 500 trials, see the text) of $1.6 \%$. Rotational light-curve of Chiron phased to a period of 5.5 hours (bottom panel).

Table 2 Photometry of 2060 Chiron ( 1977 UB); 2011 JulyAugust. All the observations in the $R$ filter; notation as in Table 1

| Julian date | A.M. | Exp. (s) | Mag | $\alpha\left(^{\circ}\right.$ ) |
| :---: | :---: | :---: | :---: | :---: |
| 2455772.717766 | 1.17 | 600 | $19.557 \pm 0.075$ | 1.64 |
| 2455772.726655 | 1.15 | 600 | $19.370 \pm 0.061$ | 1.64 |
| 2455772.738704 | 1.13 | 800 | $18.210 \pm 0.027$ | 1.64 |
| 2455772.750451 | 1.12 | 800 | $17.233 \pm 0.011$ | 1.64 |
| 2455772.761412 | 1.11 | 800 | $17.325 \pm 0.012$ | 1.64 |
| 2455772.772199 | 1.10 | 800 | $16.899 \pm 0.008$ | 1.64 |
| 2455772.783102 | 1.11 | 800 | $16.864 \pm 0.007$ | 1.64 |
| 2455772.793854 | 1.11 | 800 | $16.864 \pm 0.008$ | 1.63 |
| 2455772.804618 | 1.12 | 800 | $16.875 \pm 0.008$ | 1.63 |
| 2455772.815347 | 1.14 | 800 | $16.866 \pm 0.008$ | 1.63 |
| 2455772.829167 | 1.17 | 800 | $16.869 \pm 0.008$ | 1.63 |
| 2455772.840347 | 1.20 | 800 | $17.156 \pm 0.009$ | 1.63 |
| 2455772.850046 | 1.24 | 600 | $17.347 \pm 0.011$ | 1.63 |
| 2455772.858657 | 1.27 | 600 | $17.202 \pm 0.010$ | 1.63 |
| 2455772.867060 | 1.32 | 600 | $17.197 \pm 0.010$ | 1.63 |
| 2455772.875475 | 1.36 | 600 | $17.188 \pm 0.010$ | 1.63 |
| 2455772.883889 | 1.42 | 600 | $17.190 \pm 0.010$ | 1.63 |
| 2455772.892292 | 1.48 | 600 | $17.191 \pm 0.010$ | 1.63 |
| 2455772.900706 | 1.56 | 600 | $17.227 \pm 0.010$ | 1.63 |
| 2455772.909144 | 1.64 | 600 | $17.202 \pm 0.011$ | 1.63 |
| 2455775.694271 | 1.22 | 600 | $17.714 \pm 0.015$ | 1.48 |
| 2455775.702766 | 1.19 | 600 | $19.942 \pm 0.117$ | 1.48 |
| 2455775.712813 | 1.16 | 600 | $19.013 \pm 0.049$ | 1.48 |
| 2455775.723380 | 1.14 | 900 | $19.542 \pm 0.097$ | 1.48 |
| 2455775.746100 | 1.11 | 900 | $18.439 \pm 0.034$ | 1.48 |
| 2455775.758449 | 1.11 | 900 | $17.691 \pm 0.020$ | 1.48 |
| 2455775.770694 | 1.10 | 900 | $16.889 \pm 0.008$ | 1.48 |
| 2455775.792616 | 1.12 | 900 | $16.938 \pm 0.009$ | 1.48 |
| 2455775.805799 | 1.14 | 900 | $16.718 \pm 0.007$ | 1.48 |
| 2455775.816470 | 1.16 | 600 | $17.972 \pm 0.020$ | 1.48 |
| 2455775.860116 | 1.33 | 600 | $17.992 \pm 0.020$ | 1.47 |
| 2455775.871898 | 1.39 | 600 | $17.700 \pm 0.016$ | 1.47 |
| 2455775.880336 | 1.46 | 600 | $17.546 \pm 0.013$ | 1.47 |
| 2455775.888762 | 1.53 | 600 | $17.591 \pm 0.015$ | 1.47 |
| 2455775.897187 | 1.61 | 600 | $17.265 \pm 0.011$ | 1.47 |
| 2455775.905613 | 1.70 | 600 | $17.464 \pm 0.014$ | 1.47 |
| 2455775.914039 | 1.82 | 600 | $17.210 \pm 0.011$ | 1.47 |
| 2455779.679375 | 1.23 | 600 | $17.099 \pm 0.011$ | 1.27 |
| 2455779.687778 | 1.20 | 600 | $17.109 \pm 0.011$ | 1.27 |
| 2455779.697523 | 1.17 | 600 | $17.076 \pm 0.010$ | 1.27 |
| 2455779.705926 | 1.15 | 600 | $17.033 \pm 0.010$ | 1.27 |
| 2455779.714317 | 1.14 | 600 | $16.623 \pm 0.006$ | 1.27 |
| 2455779.722847 | 1.12 | 600 | $16.808 \pm 0.008$ | 1.27 |
| 2455779.731238 | 1.11 | 600 | $17.138 \pm 0.028$ | 1.27 |
| 2455779.765116 | 1.11 | 600 | $17.047 \pm 0.059$ | 1.26 |
| 2455779.773600 | 1.11 | 600 | $16.797 \pm 0.007$ | 1.26 |
| 2455779.781991 | 1.12 | 600 | $17.099 \pm 0.011$ | 1.26 |
| 2455779.790394 | 1.13 | 600 | $17.092 \pm 0.009$ | 1.26 |
| 2455779.814792 | 1.18 | 900 | $16.856 \pm 0.010$ | 1.26 |
| 2455779.825417 | 1.22 | 600 | $17.123 \pm 0.010$ | 1.26 |
| 2455779.833854 | 1.25 | 600 | $17.108 \pm 0.010$ | 1.26 |
| 2455779.842245 | 1.29 | 600 | $17.099 \pm 0.009$ | 1.26 |
| 2455779.850694 | 1.34 | 600 | $17.134 \pm 0.010$ | 1.26 |
| 2455779.859097 | 1.39 | 600 | $17.231 \pm 0.010$ | 1.26 |
| 2455779.867488 | 1.44 | 600 | $17.138 \pm 0.009$ | 1.26 |
| 2455779.876146 | 1.51 | 600 | $17.113 \pm 0.009$ | 1.26 |
| 2455779.884560 | 1.59 | 600 | $17.140 \pm 0.009$ | 1.26 |
| 2455779.893032 | 1.69 | 600 | $17.144 \pm 0.010$ | 1.26 |
| 2455779.901435 | 1.80 | 600 | $17.133 \pm 0.010$ | 1.26 |

of $119 \pm 5 \mathrm{~km}$ (Fornasier et al. 2014), and a dense ring system (Braga-Ribas et al. 2014; Duffard et al. 2014). Due to the rings, the average value of the albedo, $4.2 \%$ (Fornasier et al. 2014), is variable (Duffard et al. 2014). $V R I$ photometry of Chariklo was obtained in 2006 June and again in 2011 July-August using the same equipment. During the first observing run, Chariklo was in Hydra and the observations were completed during 5 nights, 3 (2006 June 26, 28 and 29) of them photometric. During the second run, that lasted 6 nights, Chariklo was in Lupus. These nights were not photometric and only frames in the $R$-band were collected.

For the first observing run, preliminary processing of the CCD frames was made as described in Sect. 2. The average seeing was $1^{\prime \prime} 20$ along the entire 5 nights run (2006 June 26 to 30 ). The sky motion of Chariklo during this first run was $0.071^{\prime \prime} /$ minute and the typical exposure time was 400 s ; therefore, the expected shift within a given image is again well within the seeing disk. The average geocentric distance of Chariklo during the observing run was $\bar{\Delta}=12.98 \mathrm{AU}$, the average heliocentric distance was $\bar{r}=13.20 \mathrm{AU}$, and the average phase angle (Earth-Chariklo-Sun angle) was $\bar{\alpha}=4.35$. On each of the photometric nights, we observed 96 standard stars extracted from repeated observations of the four fields Mark A, PG 1657, PG 2213 and SA 110 (Landolt 1992) at different airmasses. Aperture photometry of standard stars was obtained with an aperture radius of $6{ }^{\prime \prime} .09$ (14 pixels). The instrumental photometry of Chariklo and several field stars was extracted with the DAOPHOTII (Stetson 1987) package, with a fitting radius of 5 pixels. We used five stable field stars as reference to shift Chariklo's magnitudes to the first night (June 27th), which was photometric. We then estimated aperture corrections for the field stars, that we applied to Chariklo's measurements - see Carraro et al. (2006) and Galiazzo (2009) for further details. This correction turned out to be smaller than 0.10 mag in all filters. Table 3 is analogous in structure to Table 1 and includes Chariklo's data details for the 2006 run; the associated astrometry can be found in Table 12. The data are plotted in Fig. 2, top panel.

The periodogram for the first run (Fig. 2, middle panel) shows a broad minimum between 6.8 and 7.3 h . Our best fit for the rotational period is $P=7.0 \pm 0.6 \mathrm{~h}$ (or a frequency of $0.142 \pm 0.013$ rotations per hour). The probability that there is no period with value $P$ is $4.2 \pm 0.9 \%$ and that of the observations containing a period that is different from $P$ is $0.2 \pm 0.2 \%$. The lightcurve of Chariklo in Fig. 2 bottom panel, represents the detrended data from the top panel phased with the best-fit period. Our sparse curve matches well that in fig. 1 of Fornasier et al. (2014), which has an amplitude
of 0.11 mag: it displays asymmetric double peaks and an amplitude of $\sim 0.13 \mathrm{mag}$. The amplitude in Lacerda \& Luu (2006) is about 0.1 mag . The rings affect the amplitude of the overall rotational light-curve as their aspect angle changes over time (Duffard et al. 2014). The value of the absolute magnitude in $V$ found by Fornasier et al. (2014) is $7.03 \pm 0.10 \mathrm{mag}$; our determination (found as described in Sect. 3), $7.24 \pm 0.08 \mathrm{mag}$, is compatible with this value. Consistently with results in Fornasier et al. (2014) and Duffard et al. (2014) no coma was detected (but see Sect. 8 for additional details).

Regarding the colour indices, the values found for Chariklo were $B-V=0.80 \pm 0.05, V-R=0.62 \pm 0.07$, and $R-I=0.61 \pm 0.07$. Again, the values are consistent with some already published for this object (e.g. Hainaut \& Delsanti 2002). However, they are different from those in Fulchignoni et al. (2008): $V-R=0.48$, $V-I=1.01$. These significant differences may be the result of changes in the appearance of the rings that induce variations in the overall spectral properties of this object as the absorption band due to water ice disappears when the rings are edge-on (Duffard et al. 2014; Fornasier et al. 2014).

Conditions during the second run were less favourable with the seeing changing in the range $1^{\prime \prime} 2-2^{\prime \prime} 0$. No standard stars were used in this case. As the nights were not photometric, no attempt is made to calibrate with respect to standards (see Tables 4 and 13). Apparent magnitudes in Table 4 are relative to two suitable reference field stars (not known variables) close to the target body. The average geocentric distance of Chariklo during this second observing run was $\bar{\Delta}=13.72 \mathrm{AU}$, the average heliocentric distance was $\bar{r}=14.08 \mathrm{AU}$, and the average phase angle was $\bar{\alpha}=3.9$.

## 538628 Huya (2000 EB ${ }_{173}$ )

Huya is a TNO trapped in a $3: 2$ mean motion resonance with Neptune, it is therefore a Plutino. Its diameter could be as large as $458 \pm 9 \mathrm{~km}$, with an albedo of $8.3 \pm 0.4 \%$ (Fornasier et al. 2013). Thirouin et al. (2014) give a value of 5.28 h for the rotational period of this object; Ortiz et al. (2003) derived a value of 6.75 h . Huya was observed with Chiron and Chariklo in 2006 June (see Tables 5 and 14); it was in Virgo. The average geocentric distance of Huya during the observing run was $\bar{\Delta}=28.59 \mathrm{AU}$, the average heliocentric distance was $\bar{r}=29.03 \mathrm{AU}$, and the average phase angle (Earth-Huya-Sun angle) was $\bar{\alpha}=1.8$. The periodogram in Fig. 3. middle panel, shows several minima. Our best fit for the rotational period is $P=4.45 \pm 0.07 \mathrm{~h}$ (or a

Table 3 Photometry of 10199 Chariklo ( $1997 \mathrm{CU}_{26}$ ); 2006 June. Notation as in Table 1

| Julian date | Filter | A.M. | Exp. (s) | Mag | $\alpha\left(^{\circ}\right)$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 2453914.450405 | $R$ | 1.00 | 300 | $18.011 \pm 0.050$ | 4.34 |
| 2453914.462315 | $R$ | 1.00 | 400 | $18.115 \pm 0.017$ | 4.34 |
| 2453914.474676 | $R$ | 1.01 | 400 | $18.076 \pm 0.012$ | 4.34 |
| 2453914.487072 | $R$ | 1.02 | 400 | $18.093 \pm 0.021$ | 4.34 |
| 2453914.539294 | $R$ | 1.14 | 400 | $18.147 \pm 0.027$ | 4.34 |
| 2453914.545313 | $R$ | 1.16 | 400 | $18.177 \pm 0.021$ | 4.34 |
| 2453914.578819 | $R$ | 1.32 | 400 | $18.154 \pm 0.026$ | 4.34 |
| 2453914.584850 | $R$ | 1.36 | 400 | $18.166 \pm 0.020$ | 4.34 |
| 2453914.617986 | $R$ | 1.65 | 400 | $18.076 \pm 0.030$ | 4.34 |
| 2453915.473970 | $R$ | 1.01 | 400 | $18.196 \pm 0.048$ | 4.35 |
| 2453915.489641 | $R$ | 1.03 | 400 | $18.118 \pm 0.053$ | 4.35 |
| 2453916.453565 | $R$ | 1.00 | 400 | $18.264 \pm 0.028$ | 4.36 |
| 2453916.458426 | $R$ | 1.00 | 400 | $18.301 \pm 0.018$ | 4.36 |
| 2453916.463299 | $R$ | 1.01 | 400 | $18.261 \pm 0.016$ | 4.36 |
| 2453916.510891 | $R$ | 1.07 | 400 | $18.178 \pm 0.033$ | 4.36 |
| 2453916.535081 | $R$ | 1.14 | 400 | $18.179 \pm 0.020$ | 4.36 |
| 2453916.560914 | $R$ | 1.25 | 400 | $18.209 \pm 0.023$ | 4.37 |
| 2453916.586921 | $R$ | 1.40 | 500 | $18.239 \pm 0.015$ | 4.37 |
| 2453916.613403 | $R$ | 1.65 | 500 | $18.257 \pm 0.017$ | 4.37 |
| 2453914.456100 | $V$ | 1.00 | 400 | $18.677 \pm 0.024$ | 4.34 |
| 2453914.468484 | $V$ | 1.01 | 400 | $18.709 \pm 0.027$ | 4.34 |
| 2453914.480833 | $I$ | 1.01 | 400 | $17.542 \pm 0.018$ | 4.34 |



Fig. 2 Same as Fig. 1 but for Chariklo; $4 \times 19$ test frequencies. The lowest value of the normalized power corresponds to a rotation period of $7.0 \pm 0.6 \mathrm{~h}$ or a frequency of $0.142 \pm 0.013$ cycles $/ \mathrm{h}$ with a false alarm probability $<$ $4.5 \%$. The bottom panel shows the rotational light-curve of Chariklo phased to a period of 7.0 hours.

Table 4 Photometry of 10199 Chariklo ( $1997 \mathrm{CU}_{26}$ ); 2011 July-August. All the observations in the $R$ filter.

| Julian date | A.M. | Exp. (s) | Mag | $\alpha\left(^{\circ}\right)$ |
| :---: | :---: | :---: | :---: | :---: |
| 2455772.543628 | 1.05 | 600 | $18.317 \pm 0.013$ | 3.83 |
| 2455772.584763 | 1.14 | 800 | $18.523 \pm 0.232$ | 3.83 |
| 2455772.600174 | 1.20 | 800 | $18.321 \pm 0.047$ | 3.83 |
| 2455772.611632 | 1.24 | 800 | $18.282 \pm 0.029$ | 3.83 |
| 2455772.622697 | 1.29 | 800 | $18.243 \pm 0.040$ | 3.83 |
| 2455772.634063 | 1.36 | 800 | $18.284 \pm 0.030$ | 3.83 |
| 2455772.645208 | 1.43 | 800 | $18.312 \pm 0.054$ | 3.83 |
| 2455772.656111 | 1.51 | 800 | $18.518 \pm 0.138$ | 3.83 |
| 2455775.527824 | 1.04 | 600 | $18.286 \pm 0.018$ | 3.90 |
| 2455775.536250 | 1.06 | 600 | $18.249 \pm 0.037$ | 3.90 |
| 2455775.553137 | 1.09 | 600 | $18.259 \pm 0.021$ | 3.90 |
| 2455775.561562 | 1.11 | 600 | $18.246 \pm 0.020$ | 3.90 |
| 2455775.569988 | 1.13 | 600 | $18.213 \pm 0.018$ | 3.90 |
| 2455775.578426 | 1.15 | 600 | $18.215 \pm 0.024$ | 3.90 |
| 2455775.586863 | 1.18 | 600 | $18.225 \pm 0.023$ | 3.90 |
| 2455775.595289 | 1.21 | 600 | $18.240 \pm 0.020$ | 3.90 |
| 2455775.603727 | 1.25 | 600 | $18.210 \pm 0.020$ | 3.90 |
| 2455775.616771 | 1.31 | 600 | $18.185 \pm 0.021$ | 3.90 |
| 2455775.626400 | 1.37 | 600 | $18.205 \pm 0.020$ | 3.90 |
| 2455775.670139 | 1.74 | 600 | $18.267 \pm 0.019$ | 3.90 |
| 2455775.678553 | 1.85 | 600 | $18.249 \pm 0.020$ | 3.90 |
| 2455778.509792 | 1.03 | 600 | $18.234 \pm 0.026$ | 3.95 |
| 2455778.518194 | 1.04 | 600 | $18.264 \pm 0.028$ | 3.95 |
| 2455778.526620 | 1.05 | 600 | $18.256 \pm 0.023$ | 3.95 |
| 2455778.536684 | 1.07 | 600 | $18.266 \pm 0.029$ | 3.95 |
| 2455778.545590 | 1.09 | 600 | $18.262 \pm 0.022$ | 3.95 |
| 2455778.573171 | 1.16 | 600 | $18.301 \pm 0.019$ | 3.95 |
| 2455778.581586 | 1.19 | 600 | $18.300 \pm 0.024$ | 3.95 |
| 2455778.619340 | 1.37 | 600 | $18.307 \pm 0.020$ | 3.95 |
| 2455778.627755 | 1.43 | 600 | $18.277 \pm 0.020$ | 3.95 |
| 2455778.636169 | 1.49 | 600 | $18.270 \pm 0.018$ | 3.95 |
| 2455778.644676 | 1.57 | 600 | $18.226 \pm 0.019$ | 3.95 |
| 2455778.653090 | 1.65 | 600 | $18.226 \pm 0.020$ | 3.95 |
|  |  |  |  |  |
| 2 |  |  |  |  |

frequency of $0.225 \pm 0.003$ rotations per hour). This is close to one of the aliases in Thirouin et al. (2014), 4.31 h. The probability that there is no period with value $P$ is $32.5 \pm 2.1 \%$ and that of the observations containing a period that is different from $P$ is $1.0 \pm 0.4 \%$. The light-curve of Huya in Fig. 3, bottom panel, represents the detrended data from the top panel phased with the best-fit period. Our sparse curve looks similar to that in fig. 11 of Thirouin et al. (2014), its amplitude is $\sim 0.1$ mag. For Huya, we found the following values of the colours: $B-V=1.00 \pm 0.06, V-R=0.58 \pm 0.09$, and $R-I=0.64 \pm 0.20$. These are compatible with those in e.g. Hainaut \& Delsanti (2002).

## 628978 Ixion (2001 KX $\mathbf{K i}^{\text {) }}$

Ixion is also a Plutino, one of the largest known. Lellouch et al. (2013) give a value of the diameter of $617 \pm 20 \mathrm{~km}$, with an albedo of $14.1 \pm 1.1 \%$. A rotational period of 15.9 h has been derived by Rousselot \& Petit (2010). Ixion was observed in 2010 May (see Tables 6 and 15) when the object was in Ophiuchus with the same equipment used for the previous three objects. The average geocentric distance of Ixion during the observing run was $\bar{\Delta}=40.48 \mathrm{AU}$, the average heliocentric distance was $\bar{r}=41.38 \mathrm{AU}$, and the average phase angle (Earth-Ixion-Sun angle) was $\bar{\alpha}=0.6$. The periodogram in Fig. 4 middle panel, shows several minima. Our best fit for the rotational period is $P$ $=12.4 \pm 0.3 \mathrm{~h}$ (or a frequency of $0.080 \pm 0.002$ rotations per hour). The light-curve is rather flat and the error bars are nearly as large as the purported photometric amplitude. The probability that there is no period with value $P$ is $1.2 \pm 0.5 \%$ and that of the observations containing a period that is different from $P$ is $<0.01 \%$. The light-curve of Ixion in Fig. 4, bottom panel, represents the detrended data from the top panel phased with the best-fit period. Unfortunately, the data sampling was rather incomplete. No evidence of cometary activity was found in our CCD frames; this result is consistent with those from previous studies (e.g. Lorin \& Rousselot 2007). Ixion was also observed in 2006 (see Table 16), but no useful data were acquired other than astrometry. The average geocentric distance of Ixion during this previous observing run was $\bar{\Delta}=41.34 \mathrm{AU}$, the average heliocentric distance was $\bar{r}=42.25 \mathrm{AU}$, and the average phase angle was $\bar{\alpha}=0.6$.

## 790482 Orcus (2004 DW)

Also a Plutino, Orcus is the largest of the objects studied in this paper. Its diameter amounts to $917 \pm 25 \mathrm{~km}$




Fig. 3 Same as Fig. 1 but for Huya; $4 \times 18$ test frequencies. The lowest value of the normalized power corresponds to a rotation period of $4.45 \pm 0.07 \mathrm{~h}$ or a frequency of $0.225 \pm 0.003$ cycles $/ \mathrm{h}$ with a false alarm probability $<33 \%$. The bottom panel shows the rotational light-curve of Huya phased to a period of 4.45 h .

Table 5 Photometry of 38628 Huya ( $2000 \mathrm{~EB}_{173}$ ); 2006 June. Notation as in Table 1

| Julian date | Filter | A.M. | Exp. (s) | Mag | $\alpha\left(^{\circ}\right)$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 2453914.494178 | $R$ | 1.15 | 400 | $19.209 \pm 0.029$ | 1.82 |
| 2453914.506551 | $R$ | 1.14 | 400 | $19.168 \pm 0.034$ | 1.82 |
| 2453914.519028 | $R$ | 1.13 | 400 | $19.167 \pm 0.032$ | 1.82 |
| 2453914.552604 | $R$ | 1.15 | 400 | $19.199 \pm 0.038$ | 1.82 |
| 2453914.558831 | $R$ | 1.15 | 400 | $19.207 \pm 0.035$ | 1.82 |
| 2453914.592060 | $R$ | 1.24 | 400 | $19.173 \pm 0.040$ | 1.82 |
| 2453914.598079 | $R$ | 1.26 | 400 | $19.193 \pm 0.038$ | 1.82 |
| 2453914.624873 | $R$ | 1.39 | 400 | $19.263 \pm 0.041$ | 1.82 |
| 2453914.643403 | $R$ | 1.53 | 400 | $19.204 \pm 0.046$ | 1.82 |
| 2453914.649433 | $R$ | 1.59 | 400 | $19.275 \pm 0.048$ | 1.82 |
| 2453916.471181 | $R$ | 1.18 | 400 | $19.351 \pm 0.045$ | 1.84 |
| 2453916.477211 | $R$ | 1.17 | 400 | $19.359 \pm 0.042$ | 1.84 |
| 2453916.483241 | $R$ | 1.16 | 400 | $19.274 \pm 0.038$ | 1.84 |
| 2453916.518438 | $R$ | 1.13 | 500 | $19.352 \pm 0.042$ | 1.84 |
| 2453916.543808 | $R$ | 1.14 | 600 | $19.253 \pm 0.035$ | 1.84 |
| 2453916.569086 | $R$ | 1.18 | 600 | $19.255 \pm 0.039$ | 1.84 |
| 2453916.595590 | $R$ | 1.26 | 600 | $19.351 \pm 0.037$ | 1.85 |
| 2453916.621944 | $R$ | 1.40 | 600 | $19.279 \pm 0.070$ | 1.85 |
| 2453916.663704 | $R$ | 1.63 | 600 | $20.790 \pm 0.578$ | 1.85 |
| 2453914.500347 | $V$ | 1.14 | 400 | $19.784 \pm 0.023$ | 1.82 |
| 2453914.631030 | $V$ | 1.43 | 400 | $19.791 \pm 0.029$ | 1.82 |
| 2453914.512812 | $I$ | 1.13 | 400 | $18.575 \pm 0.028$ | 1.82 |
| 2453914.637211 | $I$ | 1.48 | 400 | $18.564 \pm 0.026$ | 1.82 |

Table 6 Photometry of 28978 Ixion (2001 KX ${ }_{76}$ ); 2010 May. All the observations in the $R$ filter; differential magnitudes are used.

| Julian date | Mag |
| :---: | :---: |
| 2455327.7814 | $1.099 \pm 0.056$ |
| 2455327.7913 | $1.091 \pm 0.039$ |
| 2455327.7997 | $1.069 \pm 0.049$ |
| 2455327.8198 | $0.981 \pm 0.053$ |
| 2455327.8297 | $1.048 \pm 0.047$ |
| 2455327.8387 | $1.008 \pm 0.049$ |
| 2455327.8723 | $1.028 \pm 0.070$ |
| 2455327.8897 | $1.009 \pm 0.062$ |
| 2455327.8982 | $0.997 \pm 0.052$ |
| 2455327.9128 | $0.993 \pm 0.037$ |
| 2455327.9150 | $0.988 \pm 0.041$ |
| 2455327.9234 | $1.000 \pm 0.037$ |
| 2455328.8044 | $0.978 \pm 0.049$ |
| 2455328.8132 | $0.971 \pm 0.050$ |
| 2455328.8241 | $1.052 \pm 0.052$ |
| 2455328.8329 | $1.064 \pm 0.054$ |
| 2455328.8419 | $1.011 \pm 0.049$ |
| 2455328.8504 | $0.985 \pm 0.043$ |
| 2455328.8588 | $1.067 \pm 0.050$ |
| 2455328.8672 | $1.068 \pm 0.051$ |
| 2455328.8840 | $1.026 \pm 0.060$ |
| 2455328.8925 | $1.010 \pm 0.050$ |
| 2455328.9177 | $1.062 \pm 0.069$ |
| 2455328.9261 | $0.982 \pm 0.059$ |
| 2455328.9346 | $0.995 \pm 0.053$ |
| 2455328.9431 | $1.005 \pm 0.051$ |
| 2455328.9515 | $1.029 \pm 0.052$ |
| 2455328.9599 | $1.050 \pm 0.066$ |
| 2455328.9683 | $1.027 \pm 0.061$ |
| 2455328.9767 | $1.087 \pm 0.044$ |
| 2455328.9852 | $1.051 \pm 0.050$ |
| 2455328.9959 | $1.011 \pm 0.074$ |
| 2455329.0164 | $0.986 \pm 0.050$ |
| 2455329.0263 | $1.003 \pm 0.049$ |
| 2455329.0347 | $1.037 \pm 0.049$ |
| 2455329.0431 | $1.090 \pm 0.055$ |
| 2455329.0516 | $1.064 \pm 0.047$ |
| 2455329.0600 | $1.035 \pm 0.053$ |
|  | $0.979 \pm 0.052$ |

with an albedo of $23 \pm 2 \%$ (Fornasier et al. 2013). Rabinowitz et al. (2007) give a value of 13.188 h for the rotational period of this object. Fornasier et al. (2013) suggest 10.47 h based on Thirouin et al. (2010) that gives an amplitude of $0.04 \pm 0.01 \mathrm{mag}$; a similar estimate is also given in Ortiz et al. (2006). Orcus has a known companion, Vanth, whose mass is comparable to that of the primary (Brown et al. 2010); its diameter is estimated to be $276 \pm 17 \mathrm{~km}$ (Fornasier et al. 2013). This may induce tidally locked rotation in the pair and Ortiz et al. (2011) have found possible evidence of this in the form of a photometric variability with a period of $9.7 \pm 0.3$ days. Orcus was observed in 2010 May (see Tables 7 and 17) and again in 2011 January (see Tables 8 and (18) when it was in Sextans with the same equipment used for the previous four objects. The average geocentric distance of Orcus during the first observing run was $\bar{\Delta}=47.73 \mathrm{AU}$, the average heliocentric distance was $\bar{r}=47.90 \mathrm{AU}$, and the average phase angle (Earth-Orcus-Sun angle) was $\bar{\alpha}=1.2$; the respective values for the second observing run were 47.29 AU, 47.92 AU and 0.9 . The periodogram in Fig. 5. middle panel, results from the analysis of the second run and shows several minima. Our best fit for the rotational period is $P=11.9 \pm 0.5 \mathrm{~h}$ (or a frequency of $0.084 \pm 0.004$ rotations per hour). Unfortunately, the light-curve is rather flat and incomplete; it resembles those in figs. 18 and 19 in Sheppard (2007) that show an amplitude $<0.03 \mathrm{mag}$. The probability that there is no period with value $P$ is $>90 \%$. The light-curve of Orcus in Fig. 5] bottom panel, represents the data from the top panel phased with the best-fit period and exhibits a photometric amplitude of $\sim 0.05$ which is similar in value to the error bars and also to the values cited in the literature. Small amplitude light-curves are characteristic of spherical objects with featureless surfaces and/or those observed under a nearly pole-on viewing geometry.

## 8 Discussion and conclusions

We have collected and analysed $R$-band photometric data for two Centaurs and three TNOs. In principle, our analysis confirms the published values of the rotational periods of Chiron, Chariklo, and Huya; the photometric amplitudes found are, in general, consistent with those quoted in the literature. These also exhibit notable dispersions, in particular those of Chiron. This may hint at changing surface features or, perhaps, chaotic rotation. Both Ixion and Orcus show behaviour compatible with no variability within the photometric uncertainties. Assuming that the data are reliable, lack


Fig. 4 Same as Fig. 1 but for Ixion, data obtained in 2010 May; $4 \times 39$ test frequencies. The lowest value of the normalized power corresponds to a rotation period of $12.4 \pm 0.3$ $h$ or a frequency of $0.080 \pm 0.002$ cycles $/ \mathrm{h}$ with a false alarm probability $<2 \%$. The bottom panel shows the rotational light-curve of Ixion phased to a period of 12.4 h .


Fig. 5 Same as Fig. 1 but for Orcus, data obtained in 2011 January; $4 \times 36$ test frequencies. The lowest value of the normalized power corresponds to a rotation period of $11.9 \pm 0.5 \mathrm{~h}$ or a frequency of $0.084 \pm 0.004$ cycles $/ \mathrm{h}$ with a false alarm probability $>90 \%$. The bottom panel shows the rotational light-curve of Orcus phased to a period of 11.9 h .
of brightness variation may have its origin in slow spin, being viewed nearly pole-on, and/or round shape. In general, our rotational period results could be uncertain by a few tens of percent as they are based on less than full coverage of the light-curve. As for the overall rotational properties of Centaurs and TNOs, the extensive analysis in Thirouin et al. (2014) shows that single TNOs tend to spin faster than binaries. On the other hand, resonant TNOs (Plutinos in particular) are less prone to suffer planetary close encounters, such dynamical events may alter the rotational properties of Centaurs that are more likely to experience tidal interactions with the Jovian planets. In this context, the current values of the rotational periods of Chiron and Chariklo may not be primordial.

Visual inspection and measurements of the FWHM of the objects studied here and neighbouring star images did not reveal the presence of a coma around them. As an example, Fig. 6 compares the brightness profile of Chiron (first run) with that of a scaled background star. Their profiles are indistinguishable in all directions. Since the radial profile of Chiron is basically identical to that of the comparison stars, we conclude that a coma around Chiron was not present or it was well beyond our detection limit (order of $27.18 \mathrm{mag} / \operatorname{arcsec}^{2}$ ) -if present at all. The absence of a detectable coma is compatible with the results in Fornasier et al. (2013). In order to constrain the possible presence of a coma, we use the relation given by Jewitt \& Danielson (1984)

$$
\begin{equation*}
\Sigma(\phi)=m(\phi)+2.5 \log \left(2 \pi \phi^{2}\right) \tag{4}
\end{equation*}
$$

where $m(\phi)$ is the total magnitude of the coma inside a circle of radius $\phi$ in arcsec and $\Sigma(\phi)$ is the surface brightness at projected radius $\phi$. The upper limit to the surface brightness of a hypothetical coma around the object at $\phi=2^{\prime \prime} 175$ (almost double the seeing) can be set to be $27.18 \mathrm{mag} / \operatorname{arcsec}^{2}$ as $m\left(2^{\prime \prime} 175\right)>20 \mathrm{mag}$ in $R$. This is 3.49 mag fainter (factor of 25 ) than the limiting value for a single frame as 25 of them were coadded; for a SNR of 10 the limiting magnitude is 20 mag . Consistently, presence of candidate satellites or comoving wide companions brighter than 23.5 mag in $R$ can also be discarded. Similar results have been obtained for the other objects. Modelling the dust production rate for Chiron or Chariklo is outside the scope of this work. The orbital solutions derived from the acquired astrometry (see Appendix A) are compatible with those already available from the JPL Small-Body Database, the MPC data server, or the AstDyS information service.

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Table 7 Photometry of 90482 Orcus (2004 DW); 2010 May. All the observations in the $R$ filter; differential magnitudes are used.

| Julian date | A.M. | Mag | $\alpha\left(^{\circ}\right)$ |
| :---: | :---: | :---: | :---: |
| 2455327.4600 | 1.09 | $0.484 \pm 0.017$ | 1.19 |
| 2455327.4684 | 1.09 | $0.506 \pm 0.016$ | 1.19 |
| 2455327.4769 | 1.09 | $0.513 \pm 0.017$ | 1.19 |
| 2455327.4854 | 1.10 | $0.536 \pm 0.014$ | 1.19 |
| 2455327.4938 | 1.10 | $0.511 \pm 0.015$ | 1.19 |
| 2455327.5028 | 1.12 | $0.524 \pm 0.017$ | 1.19 |
| 2455327.5112 | 1.13 | $0.525 \pm 0.017$ | 1.19 |
| 2455327.5196 | 1.15 | $0.496 \pm 0.013$ | 1.19 |
| 2455327.5280 | 1.17 | $0.495 \pm 0.012$ | 1.19 |
| 2453327.5364 | 1.20 | $0.521 \pm 0.013$ | 1.19 |
| 2455327.5468 | 1.23 | $0.535 \pm 0.015$ | 1.19 |
| 2455327.5552 | 1.27 | $0.527 \pm 0.013$ | 1.19 |
| 2455327.5637 | 1.32 | $0.529 \pm 0.013$ | 1.19 |
| 2455327.5721 | 1.37 | $0.515 \pm 0.011$ | 1.19 |
| 2455327.5862 | 1.47 | $0.527 \pm 0.014$ | 1.19 |
| 2455327.5947 | 1.54 | $0.547 \pm 0.015$ | 1.19 |
| 2455327.6031 | 1.62 | $0.545 \pm 0.015$ | 1.19 |



Fig. 6 The brightness profile of 2060 Chiron and that of a scaled background star (2MASS 20364099-1100046, $B=$ 18.27, $V=17.17, R=17.23$ ) illustrate the stellar appearance of the Centaur.

Table 8 Photometry of 90482 Orcus (2004 DW); 2011 January. All the observations in the $R$ filter; differential magnitudes are used.

| Julian date | A.M. | Mag | $\alpha\left(^{\circ}\right)$ |
| :---: | :---: | :---: | :---: |
| 2455565.7892 | 1.10 | $2.729 \pm 0.020$ | 0.93 |
| 2455565.7954 | 1.09 | $2.687 \pm 0.020$ | 0.93 |
| 2455565.8074 | 1.08 | $2.716 \pm 0.020$ | 0.93 |
| 2455565.8127 | 1.08 | $2.552 \pm 0.025$ | 0.93 |
| 2455565.8214 | 1.08 | $2.709 \pm 0.020$ | 0.93 |
| 2455565.8266 | 1.08 | $2.701 \pm 0.019$ | 0.92 |
| 2455565.8404 | 1.09 | $2.690 \pm 0.019$ | 0.92 |
| 2455566.0123 | 1.09 | $2.725 \pm 0.020$ | 0.92 |
| 2455566.0234 | 1.10 | $2.628 \pm 0.022$ | 0.92 |
| 2455566.0284 | 1.11 | $2.804 \pm 0.029$ | 0.92 |
| 2455567.7775 | 1.11 | $2.674 \pm 0.015$ | 0.90 |
| 2455567.7886 | 1.09 | $2.685 \pm 0.015$ | 0.90 |
| 2455567.8023 | 1.08 | $2.655 \pm 0.015$ | 0.90 |
| 2455567.8180 | 1.08 | $2.682 \pm 0.015$ | 0.90 |
| 2455567.8286 | 1.08 | $2.641 \pm 0.015$ | 0.90 |
| 2455567.8336 | 1.08 | $2.667 \pm 0.015$ | 0.90 |
| 2455567.8442 | 1.10 | $2.675 \pm 0.015$ | 0.90 |
| 2455567.8492 | 1.10 | $2.631 \pm 0.015$ | 0.90 |
| 2455568.7987 | 1.08 | $2.664 \pm 0.019$ | 0.89 |
| 2455568.8062 | 1.08 | $2.667 \pm 0.015$ | 0.89 |
| 2455568.8209 | 1.08 | $2.660 \pm 0.019$ | 0.89 |
| 2455568.9929 | 1.08 | $2.692 \pm 0.018$ | 0.89 |
| 2455568.8367 | 1.09 | $2.661 \pm 0.019$ | 0.89 |
| 2455568.8474 | 1.10 | $2.680 \pm 0.019$ | 0.89 |
| 2455568.8588 | 1.12 | $2.666 \pm 0.034$ | 0.89 |
| 2455569.8146 | 1.08 | $2.658 \pm 0.020$ | 0.88 |
| 2455569.8198 | 1.08 | $2.624 \pm 0.019$ | 0.88 |
| 2455569.8341 | 1.09 | $2.657 \pm 0.019$ | 0.88 |
| 2455569.8391 | 1.10 | $2.646 \pm 0.018$ | 0.88 |
| 2455569.8442 | 1.10 | $2.642 \pm 0.018$ | 0.88 |
| 2455569.8555 | 1.12 | $2.658 \pm 0.019$ | 0.88 |
| 2455570.7807 | 1.09 | $2.635 \pm 0.017$ | 0.87 |
| 2455570.7863 | 1.09 | $2.666 \pm 0.018$ | 0.87 |
| 2455570.8007 | 1.08 | $2.626 \pm 0.017$ | 0.87 |
| 2455570.8061 | 1.08 | $2.647 \pm 0.017$ | 0.87 |
| 2455570.8174 | 1.08 | $2.676 \pm 0.018$ | 0.87 |
| 2455570.8227 | 1.08 | $2.628 \pm 0.017$ | 0.87 |
| 245570.8339 | 1.09 | $2.656 \pm 0.017$ | 0.87 |
|  |  |  |  |

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A Astrometry of 2060 Chiron ( 1977 UB), 10199 Chariklo ( $1997 \mathrm{CU}_{26}$ ), 38628 Huya ( $2000 \mathrm{~EB}_{173}$ ), 28978 Ixion (2001 KX 76 ), and 90482 Orcus ( 2004 DW)

Table 9 Observations of 2060 Chiron (1977 UB) over interval 2006 June 26.298391-28.313276. During this observing run, Chiron was in Capricornus. See also Table 1

| Date <br> (UT) | $\begin{gathered} \mathrm{RA}(\mathrm{~J} 2000) \\ (\mathrm{h}: \mathrm{m}: \mathrm{s}) \end{gathered}$ | $\begin{gathered} \text { Dec(J2000) } \\ \left({ }^{\circ}:^{\prime}:^{\prime \prime}\right) \end{gathered}$ | Filter |
| :---: | :---: | :---: | :---: |
| 2006626.298391 | 20:36:46.81 | -11:00:29.8 | $B$ |
| 2006626.305822 | 20:36:46.72 | -11:00:30.1 | $R$ |
| 2006626.311991 | 20:36:46.67 | -11:00:30.3 | V |
| 2006626.318206 | 20:36:46.61 | -11:00:30.4 | $I$ |
| 2006626.324410 | 20:36:46.54 | -11:00:30.5 | $R$ |
| 2006626.357975 | 20:36:46.18 | -11:00:31.0 | $R$ |
| 2006626.364005 | 20:36:46.12 | -11:00:31.2 | $R$ |
| 2006626.370023 | 20:36:46.04 | -11:00:31.4 | $R$ |
| 2006626.376053 | 20:36:45.99 | -11:00:31.6 | $R$ |
| 2006626.382084 | 20:36:45.93 | -11:00:31.8 | $R$ |
| 2006626.389491 | 20:36:45.86 | -11:00:31.8 | $B$ |
| 2006626.397037 | 20:36:45.78 | -11:00:31.9 | $R$ |
| 2006626.403067 | 20:36:45.69 | -11:00:31.9 | $R$ |
| 2006626.410428 | 20:36:45.64 | -11:00:32.4 | $B$ |
| 2006628.189248 | 20:36:26.98 | -11:01:13.5 | $R$ |
| 2006628.195278 | 20:36:26.92 | -11:01:13.7 | $R$ |
| 2006628.201296 | 20:36:26.84 | -11:01:13.8 | $R$ |
| 2006628.224491 | 20:36:26.57 | -11:01:14.5 | $R$ |
| 2006628.230521 | 20:36:26.51 | -11:01:14.7 | $R$ |
| 2006628.236540 | 20:36:26.43 | -11:01:15.0 | $R$ |
| 2006628.258970 | 20:36:26.20 | -11:01:15.3 | $R$ |
| 2006628.265000 | 20:36:26.14 | -11:01:15.5 | $R$ |
| 2006628.271030 | 20:36:26.07 | -11:01:15.8 | $R$ |
| 2006628.277049 | 20:36:26.00 | -11:01:16.0 | $R$ |
| 2006628.283079 | 20:36:25.94 | -11:01:16.2 | $R$ |
| 2006628.289167 | 20:36:25.87 | -11:01:16.2 | $R$ |
| 2006628.294503 | 20:36:25.81 | -11:01:16.4 | $R$ |
| 2006628.301227 | 20:36:25.74 | -11:01:16.5 | $R$ |
| 2006628.307246 | 20:36:25.70 | -11:01:16.6 | $R$ |
| 2006628.313276 | 20:36:25.59 | -11:01:16.8 | $R$ |

Table 10 Observations of 2060 Chiron (1977 UB) over interval 2011 July 30.217766 - August 06.393033 . During this observing run, Chiron was in Aquarius. All the observations in the $R$ filter. See also Table 2

| Date (UT) | $\begin{gathered} \text { RA(J2000) } \\ \left({ }^{\mathrm{h}: \mathrm{m}: \mathrm{s})}\right. \end{gathered}$ | $\begin{gathered} \hline \text { Dec(J2000) } \\ \left({ }^{\circ}:^{\prime}:^{\prime \prime}\right) \\ \hline \end{gathered}$ |
| :---: | :---: | :---: |
| 2011730.217766 | 22:15:08.78 | -04:16:07.4 |
| 2011730.226655 | 22:15:08.68 | -04:16:07.8 |
| 2011730.238704 | 22:15:08.57 | -04:16:08.2 |
| 2011730.250452 | 22:15:08.43 | -04:16:09.0 |
| 2011730.261412 | 22:15:08.35 | -04:16:09.4 |
| 2011730.272199 | 22:15:08.24 | -04:16:09.9 |
| 2011730.283102 | 22:15:08.12 | -04:16:10.6 |
| 2011730.2 | 22:15:08.02 | -04:16:11.2 |
| 2011730.304618 | 22:15:07.91 | $-04: 16: 11.6$ |
| 2011730. | 22:15:07.82 | -04:16:12.4 |
| 2011730.329169 | 22:15:07.68 | $-04: 16: 12.8$ |
| 2011730.340347 | 22:15:07.58 | $-04: 16: 13.2$ |
| 2011730 | 22 | $-04: 16: 13.8$ |
| 2011730.358658 | 22 | -04:16:14.1 |
| 2011730.367060 | 22:15:07.30 | $-04: 16: 14.7$ |
| 2011730 | 22 | -04:16:15.0 |
| 2011730.383889 | 22:15:07.15 | $-04: 16: 15.5$ |
| 2011730 | 22:15:07.04 | $-04: 16: 15.8$ |
| 2011730 | 22 | -04:16:16.2 |
| 2011730.409144 | 22:15:06.87 | $-04: 16: 16.5$ |
| 2011730 | 22 | $-04: 16: 17.1$ |
| 2011802.194 | 22 | -04:18:31.1 |
| 2011802.202766 | 22:14:39.77 | $-04: 18: 31.7$ |
| 2011802 | 22 | - |
| 2011802.22338 | 22:14:39.57 | $-04: 18: 32.8$ |
| 2011802.246100 | 22:14:39.35 | $-04: 18: 33.8$ |
| 2011802 | 22 | -0 |
| 2011802.270695 | 22:14:39.08 | -04:18:35.4 |
| 2011802.292616 | 22:14:38.86 | $-04: 18: 36.5$ |
| 2011802.305 | 22 | - |
| 2011802.316470 | 22:14:38.63 | $-04: 18: 37.6$ |
| 2011802.360 | 22:14:38.18 | -04:18:39.6 |
| 2011802.3718 | 22:14:38 | -0 |
| 2011802.380336 | 22:14:37.99 | $-04: 18: 40.8$ |
| 2011802.388 | 22:14:37.88 | -0 |
| 2011802.397188 | 22:14:37.80 | -04:18:41.8 |
| 2011802.405614 | 22:14:37.70 | $-04: 18: 42.2$ |
| 2011802.414040 | 22:14:37.62 | -04:18:42.7 |
| 2011806.179375 | 22:13:59.81 | -04:21:57.2 |
| 2011806.187778 | 22:13:59.71 | -04:21:57.7 |
| 2011806.197523 | 22:13:59.61 | -04:21:58.3 |
| 2011806.205926 | 22:13:59.55 | -04:21:58.8 |
| 2011806.214317 | 22:13:59.43 | -04:21:59.2 |
| 2011806.222847 | 22:13:59.34 | $-04: 21: 59.7$ |
| 2011806.231239 | 22:13:59.22 | -04:21:59.9 |
| 2011806.239641 | 22:13:59.13 | -04:22:00.4 |
| 2011806.265116 | 22:13:58.96 | -04:22:01.7 |
| 2011806.273600 | 22:13:58.84 | -04:22:02.4 |
| 2011806.281991 | 22:13:58.74 | -04:22:02.8 |
| 2011806.290394 | 22:13:58.64 | -04:22:03.2 |
| 2011806.314792 | 22:13:58.39 | -04:22:04.3 |
| 2011806.325417 | 22:13:58.27 | -04:22:04.8 |
| 2011806.333854 | 22:13:58.19 | -04:22:05.2 |
| 2011806.342246 | 22:13:58.12 | -04:22:05.8 |
| 2011806.350695 | 22:13:58.03 | -04:22:06.2 |
| 2011806.359097 | 22:13:57.94 | -04:22:06.8 |
| 2011806.367489 | 22:13:57.85 | -04:22:07.3 |
| 2011806.376146 | 22:13:57.77 | -04:22:07.7 |
| 2011806.384560 | 22:13:57.68 | -04:22:08.1 |
| 2011806.393033 | 22:13:57.59 | -04:22:08.7 |
| 2011806.401435 | 22:13:57.50 | -04:22:09.0 |

Table 11 Observations of 2060 Chiron (1977 UB) over interval 2006 May 19.383990-22.438617. During this observing run, Chiron was in Aquarius.

| Date <br> $(\mathrm{UT})$ | RA(J2000) <br> $(\mathrm{h}: \mathrm{m} \cdot \mathrm{s})$ | Dec(J2000) <br> $\left({ }^{\circ}:^{\prime}:^{\prime \prime}\right)$ | Filter |
| :---: | :---: | :---: | :---: |
| 2006519.383990 | $20: 40: 46.42$ | $-11: 00: 36.5$ | $R$ |
| 2006519.389247 | $20: 40: 46.41$ | $-11: 00: 36.2$ | $V$ |
| 2006519.394501 | $20: 40: 46.39$ | $-11: 00: 36.2$ | $R$ |
| 2006519.407375 | $20: 40: 46.39$ | $-11: 00: 35.9$ | $R$ |
| 2006519.412628 | $20: 40: 46.37$ | $-11: 00: 35.9$ | $I$ |
| 2006519.417883 | $20: 40: 46.34$ | $-11: 00: 35.6$ | $R$ |
| 2006519.423152 | $20: 40: 46.33$ | $-11: 00: 35.5$ | $V$ |
| 2006519.428409 | $20: 40: 46.32$ | $-11: 00: 35.4$ | $R$ |
| 2006519.441269 | $20: 40: 46.30$ | $-11: 00: 35.1$ | $R$ |
| 2006519.446528 | $20: 40: 46.28$ | $-11: 00: 35.0$ | $I$ |
| 2006522.426946 | $20: 40: 40.18$ | $-10: 59: 32.1$ | $R$ |
| 2006522.432782 | $20: 40: 40.18$ | $-10: 59: 31.9$ | $V$ |
| 2006522.438617 | $20: 40: 40.16$ | $-10: 59: 31.8$ | $R$ |

Table 12 Observations of Chariklo over interval 2006 June 27.950405-30.113403. See also Table 3 During this observing run, Chariklo was in Hydra.

| Date <br> $(\mathrm{UT})$ | RA(J2000) <br> $(\mathrm{h} \cdot \mathrm{m}: \mathrm{s})$ | Dec(J2000) <br> $\left({ }^{\circ}::^{\prime}: \prime\right)$ | Filter |
| :---: | :---: | :---: | :---: |
| 2006627.950405 | $12: 24: 30.52$ | $-28: 28: 12.9$ | $R$ |
| 2006627.956100 | $12: 24: 30.54$ | $-28: 28: 12.5$ | $V$ |
| 2006627.962315 | $12: 24: 30.57$ | $-28: 28: 12.2$ | $R$ |
| 2006627.968484 | $12: 24: 30.59$ | $-28: 28: 11.6$ | $V$ |
| 2006627.974676 | $12: 24: 30.62$ | $-28: 28: 11.3$ | $R$ |
| 2006627.980833 | $12: 24: 30.65$ | $-28: 28: 10.7$ | $I$ |
| 2006627.987072 | $12: 24: 30.68$ | $-28: 28: 10.3$ | $R$ |
| 2006628.039294 | $12: 24: 30.93$ | $-28: 28: 06.2$ | $R$ |
| 2006628.045313 | $12: 24: 30.96$ | $-28: 28: 05.8$ | $R$ |
| 2006628.078819 | $12: 24: 31.12$ | $-28: 28: 03.2$ | $R$ |
| 2006628.084850 | $12: 24: 31.14$ | $-28: 28: 02.7$ | $R$ |
| 2006628.117986 | $12: 24: 31.31$ | $-28: 28: 00.1$ | $R$ |
| 2006628.973970 | $12: 24: 35.84$ | $-28: 26: 55.3$ | $R$ |
| 2006628.989641 | $12: 24: 35.93$ | $-28: 26: 53.9$ | $R$ |
| 2006629.953565 | $12: 24: 41.27$ | $-28: 25: 42.5$ | $R$ |
| 2006629.958426 | $12: 24: 41.30$ | $-28: 25: 42.1$ | $R$ |
| 2006629.963299 | $12: 24: 41.32$ | $-28: 25: 41.8$ | $R$ |
| 2006630.010891 | $12: 24: 41.58$ | $-28: 25: 38.3$ | $R$ |
| 2006630.035081 | $12: 24: 41.70$ | $-28: 25: 36.7$ | $R$ |
| 2006630.060914 | $12: 24: 41.85$ | $-28: 25: 34.8$ | $R$ |
| 2006630.086921 | $12: 24: 41.99$ | $-28: 25: 32.8$ | $R$ |
| 2006630.113403 | $12: 24: 42.15$ | $-28: 25: 30.7$ | $R$ |

Table 13 Observations of Chariklo over interval 2011 July 30.043623 - August 06.162685. During this observing run, Chariklo was in Lupus. All the observations in the $R$ filter. See also Table 4

| $\begin{aligned} & \hline \text { Date } \\ & \text { (UT) } \end{aligned}$ | $\begin{gathered} \text { RA(J2000) } \\ \left({ }^{\text {h }: ~}{ }^{\text {m }: \mathrm{s})}\right. \end{gathered}$ | $\begin{gathered} \hline \text { Dec(J2000) } \\ \left({ }^{\circ}:^{\prime}:^{\prime \prime}\right) \end{gathered}$ |
| :---: | :---: | :---: |
| 2011730.043623 | 15:29:12.14 | -40:01:58.6 |
| 2011730.052083 | 15:29:12.13 | -40:01:57.7 |
| 2011730.060567 | 15:29:12.13 | -40:01:56.9 |
| 2011730.074074 | 15:29:12.09 | -40:01:55.4 |
| 2011730.084757 | 15:29:12.09 | -40:01:53.9 |
| 2011730.100174 | 15:29:12.08 | -40:01:52.8 |
| 2011730.111632 | 15:29:12.07 | -40:01:51.6 |
| 2011730.122697 | 15:29:12.06 | -40:01:50.6 |
| 2011730.134063 | 15:29:12.06 | -40:01:49.5 |
| 2011730.145208 | 15:29:12.05 | -40:01:48.2 |
| 2011730.156111 | 15:29:12.05 | -40:01:47.1 |
| 2011801.994016 | 15:29:12.71 | -39:57:04.5 |
| 2011802.002535 | 15:29:12.72 | $-39: 57: 03.7$ |
| 2011802.010972 | 15:29:12.72 | -39:57:02.9 |
| 2011802.019398 | 15:29:12.73 | -39:57:02.0 |
| 2011802.027824 | 15:29:12.73 | -39:57:01.2 |
| 2011802.036250 | 15:29:12.73 | -39:57:00.4 |
| 2011802.044699 | 15:29:12.73 | -39:56:59.5 |
| 2011802.053137 | 15:29:12.74 | -39:56:58.8 |
| 2011802.061563 | 15:29:12.74 | -39:56:57.9 |
| 2011802.069988 | 15:29:12.74 | -39:56:56.9 |
| 2011802.078426 | 15:29:12.75 | -39:56:56.2 |
| 2011802.086863 | 15:29:12.75 | -39:56:55.3 |
| 2011802.095289 | 15:29:12.76 | -39:56:54.5 |
| 2011802.103727 | 15:29:12.77 | $-39: 56: 53.7$ |
| 2011802.116771 | 15:29:12.77 | $-39: 56: 52.4$ |
| 2011802.126400 | 15:29:12.77 | -39:56:51.5 |
| 2011802.135914 | 15:29:12.78 | -39:56:50.5 |
| 2011802.144352 | 15:29:12.79 | -39:56:49.6 |
| 2011802.153252 | 15:29:12.79 | -39:56:48.7 |
| 2011802.161690 | 15:29:12.79 | -39:56:47.8 |
| 2011802.170139 | 15:29:12.80 | -39:56:47.0 |
| 2011802.178553 | 15:29:12.81 | -39:56:46.2 |
| 2011805.009792 | 15:29:16.44 | -39:52:10.7 |
| 2011805.018194 | 15:29:16.45 | -39:52:09.9 |
| 2011805.026620 | 15:29:16.47 | -39:52:09.1 |
| 2011805.036678 | 15:29:16.49 | -39:52:08.3 |
| 2011805.045590 | 15:29:16.50 | -39:52:07.3 |
| 2011805.073171 | 15:29:16.54 | -39:52:04.5 |
| 2011805.081586 | 15:29:16.55 | $-39: 52: 03.7$ |
| 2011805.119340 | 15:29:16.60 | -39:52:00.0 |
| 2011805.127755 | 15:29:16.62 | -39:51:59.2 |
| 2011805.136169 | 15:29:16.63 | -39:51:58.4 |
| 2011805.144676 | 15:29:16.65 | -39:51:57.8 |
| 2011805.153090 | 15:29:16.66 | $-39: 51: 57.2$ |
| 2011806.034132 | 15:29:18.44 | -39:50:32.6 |
| 2011806.043657 | 15:29:18.46 | -39:50:31.7 |
| 2011806.053125 | 15:29:18.47 | -39:50:30.8 |
| 2011806.061586 | 15:29:18.49 | -39:50:29.9 |
| 2011806.069988 | 15:29:18.51 | -39:50:29.2 |
| 2011806.078380 | 15:29:18.52 | -39:50:28.3 |
| 2011806.086834 | 15:29:18.54 | -39:50:27.5 |
| 2011806.095231 | 15:29:18.55 | -39:50:26.7 |
| 2011806.103634 | 15:29:18.57 | -39:50:25.9 |
| 2011806.112106 | 15:29:18.58 | -39:50:25.1 |
| 2011806.120498 | 15:29:18.60 | $-39: 50: 24.3$ |
| 2011806.128900 | 15:29:18.61 | -39:50:23.5 |
| 2011806.137431 | 15:29:18.63 | -39:50:22.7 |
| 2011806.145828 | 15:29:18.65 | -39:50:21.9 |
| 2011806.154236 | 15:29:18.67 | -39:50:21.1 |
| 2011806.162685 | 15:29:18.69 | -39:50:20.3 |

Table 14 Observations of 38628 Huya ( $2000 \mathrm{~EB}_{173}$ ) over interval 2006 June 27.994178 - 30.149815. During this observing run, Huya was in Virgo. See also Table 5

| Date <br> (UT) | $\begin{gathered} \text { RA(J2000) } \\ (\mathrm{h}: \mathrm{m}: \mathrm{s}) \end{gathered}$ | $\begin{gathered} \operatorname{Dec}(\mathrm{J} 2000) \\ \left({ }^{\circ}:^{\prime}:^{\prime \prime}\right) \end{gathered}$ | Filter |
| :---: | :---: | :---: | :---: |
| 2006627.994178 | 14:12:43.60 | -01:36:27.2 | $R$ |
| 2006628.000347 | 14:12:43.58 | -01:36:27.3 | $V$ |
| 2006628.006551 | 14:12:43.55 | -01:36:27.3 | $R$ |
| 2006628.012813 | 14:12:43.55 | -01:36:27.6 | $R$ |
| 2006628.019028 | 14:12:43.53 | -01:36:27.6 | $R$ |
| 2006628.052604 | 14:12:43.47 | -01:36:27.8 | $R$ |
| 2006628.058831 | 14:12:43.44 | -01:36:27.8 | $R$ |
| 2006628.092060 | 14:12:43.37 | -01:36:28.0 | $R$ |
| 2006628.098079 | 14:12:43.34 | -01:36:28.5 | $R$ |
| 2006628.124873 | 14:12:43.30 | -01:36:28.2 | $R$ |
| 2006628.131030 | 14:12:43.29 | -01:36:28.3 | V |
| 2006628.137211 | 14:12:43.29 | -01:36:28.4 | $I$ |
| 2006628.143403 | 14:12:43.25 | -01:36:28.6 | $R$ |
| 2006628.149433 | 14:12:43.23 | -01:36:28.6 | $R$ |
| 2006629.967211 | 14:12:39.76 | -01:36:39.7 | $R$ |
| 2006629.971181 | 14:12:39.73 | -01:36:40.2 | $R$ |
| 2006629.977211 | 14:12:39.70 | -01:36:40.3 | $R$ |
| 2006629.983241 | 14:12:39.69 | -01:36:40.3 | $R$ |
| 2006630.018438 | 14:12:39.64 | -01:36:40.5 | $R$ |
| 2006630.043808 | 14:12:39.58 | -01:36:40.8 | $R$ |
| 2006630.069086 | 14:12:39.51 | -01:36:41.3 | $R$ |
| 2006630.095591 | 14:12:39.46 | -01:36:41.5 | $R$ |
| 2006630.121945 | 14:12:39.43 | -01:36:41.7 | $R$ |
| 2006630.149815 | 14:12:39.40 | -01:36:42.1 | $R$ |

Table 15 Observations of 28978 Ixion (2001 $\mathrm{KX}_{76}$ ) over interval 2010 May 9.267685 - 12.396771. During this observing run, Ixion was in Ophiuchus. See also Table 6.

| $\begin{aligned} & \hline \hline \text { Date } \\ & \text { (UT) } \end{aligned}$ | $\begin{gathered} \text { RA(J2000) } \\ \left(\mathrm{h}: \mathrm{m}^{\mathrm{s}} \mathrm{~s}\right) \end{gathered}$ | $\begin{gathered} \hline \hline \operatorname{Dec}(\mathrm{J} 2000) \\ \left({ }^{\circ}:^{\prime}:^{\prime \prime}\right) \\ \hline \end{gathered}$ |
| :---: | :---: | :---: |
| 2010509.262489 | 17:00:21.57 | -24:28:18.4 |
| 2010509.267685 | 17:00:21.54 | -24:28:18.2 |
| 2010509.272616 | 17:00:21.53 | -24:28:18.1 |
| 2010509.277558 | 17:00:21.50 | $-24: 28: 18.0$ |
| 2010509.284294 | 17:00:21.46 | -24:28:19.0 |
| 2010509.292894 | 17:00:21.43 | -24:28:17.7 |
| 2010509.301459 | 17:00:21.39 | -24:28:18.0 |
| 2010509.311817 | 17:00:21.34 | -24:28:18.1 |
| 2010511.118172 | 17:00:12.79 | -24:28:15.9 |
| 2010511.128114 | 17:00:12.73 | -24:28:15.8 |
| 2010511.136540 | 17:00:12.68 | $-24: 28: 15.7$ |
| 2010511.144861 | 17:00:12.63 | -24:28:15.9 |
| 2010511.156586 | 17:00:12.60 | -24:28:15.9 |
| 2010511.166470 | 17:00:12.55 | $-24: 28: 15.9$ |
| 2010511.175510 | 17:00:12.50 | -24:28:15.7 |
| 2010511.183924 | 17:00:12.46 | $-24: 28: 15.7$ |
| 2010511.192327 | 17:00:12.43 | $-24: 28: 15.7$ |
| 2010511.200729 | 17:00:12.40 | -24:28:15.6 |
| 2010511.209144 | 17:00:12.34 | -24:28:15.6 |
| 2010511.217847 | 17:00:12.31 | -24:28:15.6 |
| 2010511.226551 | 17:00:12.25 | $-24: 28: 15.7$ |
| 2010511.234966 | 17:00:12.23 | $-24: 28: 15.9$ |
| 2010511.243368 | 17:00:12.19 | -24:28:15.8 |
| 2010511.251783 | 17:00:12.14 | -24:28:15.7 |
| 2010511.260197 | 17:00:12.10 | $-24: 28: 15.7$ |
| 2010511.269167 | 17:00:12.06 | -24:28:15.6 |
| 2010511.277581 | 17:00:12.00 | $-24: 28: 15.7$ |
| 2010511.285984 | 17:00:11.97 | -24:28:15.6 |
| 2010511.294398 | 17:00:11.92 | -24:28:15.7 |
| 2010511.302801 | 17:00:11.91 | $-24: 28: 15.9$ |
| 2010511.321621 | 17:00:11.81 | -24:28:15.8 |
| 2010511.330579 | 17:00:11.72 | $-24: 28: 15.7$ |
| 2010511.338993 | 17:00:11.66 | -24:28:15.8 |
| 2010511.347396 | 17:00:11.65 | $-24: 28: 15.8$ |
| 2010511.355810 | 17:00:11.62 | -24:28:15.8 |
| 2010511.364213 | 17:00:11.56 | -24:28:15.8 |
| 2010511.373021 | 17:00:11.50 | $-24: 28: 15.7$ |
| 2010511.381435 | 17:00:11.45 | -24:28:15.7 |
| 2010511.389954 | 17:00:11.42 | -24:28:15.6 |
| 2010511.398368 | 17:00:11.41 | -24:28:15.6 |
| 2010512.141204 | 17:00:07.84 | $-24: 28: 14.7$ |
| 2010512.149989 | 17:00:07.83 | -24:28:14.6 |
| 2010512.160891 | 17:00:07.78 | -24:28:14.5 |
| 2010512.169734 | 17:00:07.70 | $-24: 28: 14.5$ |
| 2010512.178704 | 17:00:07.69 | -24:28:14.5 |
| 2010512.187165 | 17:00:07.62 | -24:28:14.5 |
| 2010512.195567 | 17:00:07.61 | -24:28:14.5 |
| 2010512.203993 | 17:00:07.55 | -24:28:14.6 |
| 2010512.212396 | 17:00:07.52 | $-24: 28: 14.5$ |
| 2010512.220810 | 17:00:07.48 | -24:28:14.5 |
| 2010512.229294 | 17:00:07.44 | -24:28:14.5 |
| 2010512.237709 | 17:00:07.40 | -24:28:14.5 |
| 2010512.246123 | 17:00:07.35 | -24:28:14.6 |
| 2010512.254537 | 17:00:07.30 | -24:28:14.5 |
| 2010512.262940 | 17:00:07.27 | $-24: 28: 14.5$ |
| 2010512.271366 | 17:00:07.22 | -24:28:14.5 |
| 2010512.279861 | 17:00:07.16 | -24:28:14.5 |
| 2010512.288276 | 17:00:07.15 | -24:28:14.4 |
| 2010512.296678 | 17:00:07.10 | -24:28:14.4 |
| 2010512.305093 | 17:00:07.06 | -24:28:14.4 |
| 2010512.313507 | 17:00:06.98 | -24:28:14.4 |
| 2010512.322014 | 17:00:06.97 | -24:28:14.4 |
| 2010512.332732 | 17:00:06.90 | -24:28:14.3 |
| 2010512.341146 | 17:00:06.88 | -24:28:14.3 |
| 2010512.353172 | 17:00:06.78 | -24:28:14.5 |
| 2010512.363137 | 17:00:06.73 | -24:28:14.5 |
| 2010512.371551 | 17:00:06.69 | -24:28:14.5 |
| 2010512.379954 | 17:00:06.65 | -24:28:14.6 |
| 2010512.388357 | 17:00:06.60 | -24:28:14.5 |
| 2010512.396771 | 17:00:06.56 | $-24: 28: 14.5$ |

Table 16 Observations of 28978 Ixion (2001 KX $\mathrm{K}_{76}$ ) over interval 2006 June 28.031296 - 30.257153 . During this observing run, Ixion was in Ophiuchus.

| Date <br> (UT) | $\begin{gathered} \text { RA(J2000) } \\ (\mathrm{h}: \mathrm{m}: \mathrm{s}) \end{gathered}$ | $\begin{gathered} \operatorname{Dec}(\mathrm{J} 2000) \\ \left({ }^{\circ}:^{\prime}:^{\prime \prime}\right) \end{gathered}$ |
| :---: | :---: | :---: |
| 2006628.025961 | 16:36:02.79 | -22:06:19.4 |
| 2006628.031296 | 16:36:02.75 | -22:06:19.1 |
| 2006628.065787 | 16:36:02.61 | -22:06:19.1 |
| 2006628.071806 | 16:36:02.58 | -22:06:19.0 |
| 2006628.105047 | 16:36:02.39 | -22:06:18.5 |
| 2006628.111077 | 16:36:02.36 | -22:06:18.7 |
| 2006628.156597 | 16:36:02.19 | -22:06:18.3 |
| 2006628.162801 | 16:36:02.13 | -22:06:18.4 |
| 2006628.169016 | 16:36:02.12 | -22:06:18.5 |
| 2006628.175232 | 16:36:02.08 | -22:06:18.3 |
| 2006628.181470 | 16:36:02.05 | -22:06:18.4 |
| 2006628.208438 | 16:36:01.94 | -22:06:18.3 |
| 2006628.213947 | 16:36:01.91 | -22:06:18.4 |
| 2006629.987709 | 16:35:53.81 | -22:06:09.3 |
| 2006629.991713 | 16:35:53.75 | -22:06:09.2 |
| 2006629.997743 | 16:35:53.74 | -22:06:09.2 |
| 2006630.003762 | 16:35:53.68 | -22:06:09.2 |
| 2006630.027107 | 16:35:53.60 | -22:06:09.1 |
| 2006630.052928 | 16:35:53.48 | -22:06:09.0 |
| 2006630.078287 | 16:35:53.37 | -22:06:08.7 |
| 2006630.104746 | 16:35:53.23 | -22:06:08.7 |
| 2006630.131412 | 16:35:53.09 | -22:06:08.6 |
| 2006630.159387 | 16:35:52.97 | -22:06:08.7 |
| 2006630.177928 | 16:35:52.90 | -22:06:08.5 |
| 2006630.196204 | 16:35:52.80 | -22:06:08.5 |
| 2006630.215648 | 16:35:52.71 | -22:06:08.3 |
| 2006630.236377 | 16:35:52.61 | -22:06:08.0 |
| 2006630.257153 | 16:35:52.52 | -22:06:07.7 |

Table 17 Observations of 90482 Orcus (2004 DW) over interval 2010 May 10.963438-12.100394. During this observing run, Orcus was in Sextans. See also Table 7

| Date <br> $(\mathrm{UT})$ | RA(J2000) <br> $(\mathrm{h}: \mathrm{m}: \mathrm{s})$ | Dec(J2000) <br> $\left({ }^{\circ}:^{\prime}::^{\prime \prime}\right)$ |
| :---: | :---: | :---: |
| 2010510.963438 | $09: 42: 04.42$ | $-05: 48: 59.6$ |
| 2010510.988831 | $09: 42: 04.51$ | $-05: 48: 59.7$ |
| 2010510.997269 | $09: 42: 04.54$ | $-05: 48: 59.8$ |
| 2010511.014688 | $09: 42: 04.50$ | $-05: 48: 58.0$ |
| 2010511.031505 | $09: 42: 04.49$ | $-05: 48: 57.9$ |
| 2010511.050313 | $09: 42: 04.48$ | $-05: 48: 57.4$ |
| 2010511.098172 | $09: 42: 04.47$ | $-05: 48: 56.6$ |
| 2010511.106609 | $09: 42: 04.56$ | $-05: 48: 56.8$ |
| 2010512.057917 | $09: 42: 04.74$ | $-05: 48: 37.0$ |
| 2010512.083553 | $09: 42: 04.78$ | $-05: 48: 36.8$ |
| 2010512.100394 | $09: 42: 04.84$ | $-05: 48: 35.9$ |

Table 18 Observations of 90482 Orcus (2004 DW) over interval 2011 January 04.31616 - 09.32441. During this observing run, Orcus was in Sextans. See also Table 8

|  | $\begin{aligned} & \hline \text { Date } \\ & \text { (UT) } \end{aligned}$ | $\begin{gathered} \text { RA(J2000) } \\ (\mathrm{h}: \mathrm{m}: \mathrm{s}) \end{gathered}$ | $\begin{gathered} \hline \operatorname{Dec}(\mathrm{J} 2000) \\ \left({ }^{\circ}:^{\prime}:^{\prime \prime}\right) \end{gathered}$ | Filter |
| :---: | :---: | :---: | :---: | :---: |
| 2011 | 104.31616 | 09:51:50.11 | -07:01:27.2 | B |
| 2011 | 105.31395 | 09:51:47.08 | -07:01:30.9 | V |
| 2011 | 105.34266 | 09:51:46.97 | -07:01:31.2 | $R$ |
| 2011 | 106.27920 | 09:51:44.07 | -07:01:34.3 | $R$ |
| 2011 | 106.29004 | 09:51:44.07 | -07:01:34.4 | $R$ |
| 2011 | 106.33538 | 09:51:43.92 | -07:01:34.4 | $R$ |
| 2011 | 106.35095 | 09:51:43.87 | -07:01:34.4 | $R$ |
| 2011 | 107.33845 | 09:51:40.72 | -07:01:37.1 | $R$ |
| 2011 | 109.29526 | 09:51:34.40 | -07:01:41.2 | $B$ |
| 2011 | 109.32441 | 09:51:34.32 | -07:01:41.2 | $R$ |


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