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Photometric study of Centaur (60558) 2000 EC_{98} and trans-neptunian object (55637) 2002 UX_{25} at different phase angles ☆

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Abstract

We present photometric observations of Centaur (60558) 2000 EC_{98} and trans-neptunian object (55637) 2002 UX_{25} at different phase angles and with different filters (mainly R but also V and B for some data). Results for 2000 EC_{98} are: (i) a rotation period of 26.802 ± 0.042 h if a double-peaked lightcurve is assumed, (ii) a lightcurve amplitude of 0.24 ± 0.06 for the R band, (iii) a phase curve with $H = 9.03 \pm 0.01$ and $G = -0.39 \pm 0.08$ (R filter) and $H = 9.55 \pm 0.04$ and $G = -0.50 \pm 0.35$ (V filter) or a slope of 0.17 ± 0.02 mag deg^{-1} (R filter) and 0.22 ± 0.06 (V filter), (iv) the color indices B–V $= 0.76 \pm 0.15$ and V–R $= 0.51 \pm 0.09$ (for $\alpha = 0.1$–$0.5°$) and 0.55 ± 0.08 (for $\alpha = 1.4$–$1.5°$). The rotation period is amongst the longest ever measured for Centaurs and TNOs. We also show that our photometry was not contaminated by any cometary activity down to magnitude $\simeq 27/\text{arcsec}^2$. For 2002 UX_{25} the results are: (i) a rotation period of 14.382 ± 0.001 h or 16.782 ± 0.003 h (if a double-peaked lightcurve is assumed) (ii) a lightcurve amplitude of 0.21 ± 0.06 for the R band (and the 16.782 h period), (iii) a phase curve with $H = 3.32 \pm 0.01$ and $G = +0.16 \pm 0.18$ or a slope of 0.13 ± 0.01 mag deg^{-1} (R filter), (iv) the color indices B–V $= 1.12 \pm 0.26$ and V–R $= 0.61 \pm 0.12$. The phase curve reveals also a possible very narrow and bright opposition surge. Because such a narrow surge appears only for one point it needs to be confirmed.

Keywords: Centaurs; Trans-neptunian objects; Photometry; (60558) 2000 EC_{98}; (55637) 2002 UX_{25}

1. Introduction

Kuiper belt objects (KBOs), whose existence was confirmed observationally in 1992 (Jewitt and Luu, 1993), represent important clue for the formation and early evolution of the outer Solar System. Nowadays, thanks to an important effort deployed in the search of new objects, a relatively large number of KBOs are officially repertoried (about 940 different objects, when Centaurs are included, as of July 2004). Such a sample has already permitted to develop different dynamical models designed to explain the formation of the Kuiper belt (e.g., Levison and Morbidelli, 2003).

The study of the physical properties of KBOs is more complicated, because of the faintness of these objects. So far such studies have been focused mainly on the color indices, leading to some trends in the different categories of KBOs identified by the dynamists (e.g., Doressoundiram et al., 2002; Hainaut and Delsanti, 2002). Some spectral studies, in the visible or near-infrared range, have also been conducted. Due to the very poor signal-to-noise ratio of these spectra such studies have produced, so far, limited results (Brown, 2000; Lazzarin et al., 2003; Fornasier et al., 2004).

This paper presents observational results based on a different approach of the physical properties of KBOs. This

☆ Based on observations obtained at the La Silla observatory of the European Southern Observatory (ESO) in Chile, and at the Pik Terskol observatory of the International Center for Astronomical Medical and Ecological Research (ICAMER) in Russia.

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approach consists in studying how the reflected light varies with the phase angle α (i.e., the angle Sun–KBO–Earth). Such an approach has already been used for many solid planetary surfaces, e.g., the Moon, asteroids, Saturn's ring or giant planets satellites. For these planetary bodies the opposition surge is a common phenomenon. This phenomenon is a non-linear increase in the average surface brightness as the phase angle decreases to zero.

Two causes of the opposition effect are usually considered: (1) shadow-hiding and (2) interference-enhancement, often called coherent-backscatter. Some general regolith property-dependent characteristics of each mechanism are understood, and several papers are devoted to discuss the relative contribution of both mechanism (Drossart, 1993; Helfenstein et al., 1997, 1998; Hapke et al., 1998; Nelson et al., 2000; Belskaya and Shevchenko, 2000; Shkuratov and Helfenstein, 2001; Poulet et al., 2002).

For "typical" KBOs, located at about 40 AU from the Sun, the maximum possible value of α is about 1.5°. For Centaurs, expected to have very similar physical properties to KBOs, but located closer the Sun, α can reach up to typically 6° (for a heliocentric distance of 10 AU). Compared to the properties of the opposition surges observed for asteroids, for example, which have typically a Half Width at Half Maximum of a few degrees (Belskaya and Shevchenko, 2000), such phase angle ranges can seem to be too limited to really permit an accurate physical modeling. Nevertheless the properties of the opposition surge appearing in the KBOs are not necessarily similar to the one usually observed for the asteroids. Belskaya et al. (2003) have pointed out the possibility of a very narrow (i.e., less than a few tenth of a degree) opposition surge.

The observations presented in this paper have been obtained on one Centaur—(60558) 2000 EC_{98}—and one KBO—(55637) 2002 UX_{25}—referred to hereafter as 2000 EC_{98} and 2002 UX_{25}. 2000 EC_{98} is a Centaur which was discovered on March 3, 2000, at Kitt Peak observatory by Spacewatch (Marsden, 2000). 2002 UX_{25} is a transneptunian object (TNO) classified as a "classical" and discovered on October 30, 2002, by the same telescope (Descour et al., 2002). Table 1 presents the orbital characteristics of both objects. Because of its large inclination, superior to 4.5°, 2002 UX_{25} can be classified also as a "hot" classical object. Since it has been possible to identify this object on images obtained well before its discovery (Stoss et al., 2002) its orbital elements are very accurate.

We conducted a photometric study of both objects. The main objective was to derive an observational phase function for these targets. This objective has been partially reached. Interesting results have been obtained but complementary data would be also useful to confirm the trends we have detected. This study also includes a search for cometary activity for 2000 EC_{98}.

In Section 2 the observational data are described for both targets. Section 3 presents the different aspects of our analysis of these data, and in Section 4 the results are discussed and compared with similar works already published.

Table 1
Orbital characteristics of 2000 EC_{98} and 2002 UX_{25}

Object	a (AU)	e	q (AU)	Q (AU)	i
2000 EC_{98}	10.759	0.455	5.86	15.65	4.3°
2002 UX_{25}	42.600	0.144	36.46	48.73	19.5°

2. Observations and data reduction

2.1. 2000 EC_{98}

This Centaur was observed during three different observing runs at La Silla Observatory (Chile), managed by the European Southern Observatory (ESO). Three different telescopes were used: the New Technology Telescope (NTT, a 3.5-m telescope) in April 2001, the Danish 1.54-m telescope in March 2002 and the 3.6-m telescope in April 2003. Table 2 gives the observing circumstances.

The observations conducted with the NTT had for main objective to search for a cometary coma. Different Centaurs were observed during this observing run, including 2000 EC_{98}, and both nights were dark and photometric. We used the direct imaging camera Superb-Seeing Imager (SUSI 2), equipped with two 2048 × 4096 CCDs, and with a field of view of 5.5′ × 5.5′. Given the very small plate scale of the instrument (0.0805″ pixel^{-1}) and the seeing (varying from about 0.9 to 1.3″) we used the 2 × 2 binned mode.

In order to avoid any trailing due to the proper motion of the object the exposure time was limited to 205 s, corresponding to a motion of 0.3″. Most of the images were obtained with a Bessel R filter, with some others with B and V filters, allowing an accurate determination of the magnitude of the reference stars.

The images were bias-subtracted using an averaged 2-D bias image. The resulting images were flat-fielded for instrumental sensitivity pattern removal using a combination of dome and sky flats (science frames). Using standard star images, we computed the photometric coefficients (zero points, extinction coefficients and color terms) using the

Table 2
Observing circumstances for 2000 EC_{98}

UT date	R	Δ	α	Telescope
2001 Apr. 26	15.16	14.46	2.81°	NTT
2001 Apr. 27	15.16	14.47	2.86°	NTT
2002 Mar. 18	14.90	13.90	0.11°	Danish
2002 Mar. 19	14.90	13.90	0.18°	Danish
2002 Mar. 23	14.89	13.90	0.45°	Danish
2002 Mar. 24	14.89	13.90	0.52°	Danish
2003 Apr. 10	14.50	13.55	1.36°	T 3.6-m
2003 Apr. 11	14.49	13.56	1.42°	T 3.6-m
2003 Apr. 12	14.49	13.56	1.49°	T 3.6-m

R: heliocentric distance (AU); Δ: geocentric distance (AU); α: phase angle.