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Visible and near-infrared spectroscopy of the Centaur 32532 (2001 PT_{13})⋆

ESO Large Program on TNOs and Centaurs: First spectroscopy results

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Abstract. We present photometric and spectroscopic data obtained through visible and near-infrared observations of the Centaur 32532 (2001 PT13) performed with FORS1 and ISAAC at the Very Large Telescope (VLT-ESO) within the framework of an ESO large program on the Trans-Neptunian objects (TNOs) and Centaurs. The results show evidence for a difference in the near-infrared spectral behaviour obtained during two observations carried out one month apart. In one spectrum there is the possible presence of signatures of water ice in small amounts. Two models have been proposed to interpret the surface composition of this Centaur.

Key words. Centaur – 32532 (2001 PT_{13}) – visible – near-infrared – spectroscopy – photometry

1. Introduction

A large program devoted to observations of Trans-Neptunian Objects (TNOs) and Centaur objects was started at ESO in

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⋆ Based on observations obtained at the VLT Observatory Cerro Paranal of European Southern Observatory, ESO in Chile within the framework of program 167.C-0340.

April 2001 (Boehnhardt et al. 2002a; Barucci et al. 2001). About 300 hours of observing time have been allocated to this program. The aim is to provide photometric and spectroscopic data in the visible and near-infrared ranges for a large set of objects to study the physical properties and composition of this newly discovered population.

The population of the TNOs and Centaurs may contain the pristine material residual of the formation of our planetary system (Hahn & Malhotra 1999). The investigation of their compositions can provide insights into the primordial processes that dominated the early solar nebula.

Centaurs have unstable orbits, located between those of Jupiter and Neptune, with short dynamical lifetimes. Even if their origin is still uncertain, they are believed to have formed in the external part of the solar system. Centaurs could have been ejected by gravitational instabilities and collisions from the Trans-neptunian belt to the giant planets' orbits. According to Levison et al. (2001), some of the Centaurs may have instead originated in the Oort Cloud. Today, in the framework of the ESO large program, more than 60 objects have been observed in visible photometry (*B*, *V*, *R*, *I*), about 20 in infrared photometry (*J*, *H*, and *K*), 12 in visible spectroscopy and 6 in near-infrared spectroscopy. The photometric observations have been performed in service mode, while the spectroscopic ones were done in visitor mode. The first results obtained on the visible photometric data have been submitted for publication (Boehnhardt et al. 2002b), while, in this paper, the first results obtained with the spectroscopy are presented. The observations reported here concern the Centaur 2001 PT_{13}, now numbered 32532. This observation was particularly favorable as the Centaur was observed just after its discovery and was relatively bright. Its main characteristics are listed in Table 1. Visible and near infrared spectroscopy with photometry (*B*, *V*, *R*, *I*, *J*, *H*, *K*) have been performed and the observational circumstances during the observations are reported in Table 2.

Table 1. Orbital and physical characteristics of 32532 (2001 PT_{13}). * Diameter range computed assuming an albedo between 0.05 and 0.25. ¶ Ortiz et al. (2002); and ‡ Farnham (2001).

perihelion distance (AU)	8.53
aphelion (AU)	12.74
eccentricity	0.198
inclination (degrees)	20.4
orbital period (years)	86.9
diameter (km)	95–40*
rotation period (hrs)	8.3¶–8.4‡

2. Observations

Near-infrared photometry and spectroscopy have been carried out with the Infrared-Cooled grating spectrometer ISAAC (Infrared Spectrometer And Array Camera) (`www.eso.org/instruments/isaac`) at the first Unit Telescope (Antu), while visible photometry and spectroscopy have been performed with FORS1 (FOcal Reducer/low dispersion Spectrograph) at UT3 (Melipal), both at the ESO-VLT. The object was observed during two runs (September and October, 2001; see Table 2). During the September run, the object was observed in near-infrared spectroscopy, while in October, visible spectroscopy, near-infrared spectroscopy and photometry were performed. The September run was not photometric due to the presence of thin cirrus close to the horizon.

Table 2. Observational circumstances during the observations: heliocentric distance, geocentric distance, phase angle and weather conditions.

Night	*r* (AU)	Δ (AU)	Phase (deg)	weather
10/Sep./2001	8.86	7.93	2.7	thin cirrus
08/Oct./2001	8.88	8.18	4.8	photometric
10/Oct./2001	8.88	8.20	4.9	photometric

2.1. Visible observations

The visible observations were performed using FORS1 mounted at UT3. The visible spectrum was taken using Grism 150I. The slit was 1″ wide, which corresponds to a spectral resolution of about 200. The imaging has been performed using broadband Bessel *BVRI* filters followed by nearly simultaneous spectroscopy. Both imaging and spectroscopic frames were corrected for bias and flat-field. The photometric reduction was done using the MIDAS package as described in Barucci et al. (1999). Extintion coefficients, colour terms and zero points for photometric calibrations were provided by the FORS1 calibration plan (`http://www.eso.org/observing/dfo/quality/FORS/qc/zeropoints`). These parameters are computed during each observing night via a one-step multilinear least squares fit to the data produced by pipeline routine at ESO, on the basis of several standards from the Landolt catalogue (Landolt 1992) observed each night. The pipeline extracts magnitudes using SS Extractor (Bertin & Arnouts 1996) with a fixed radius aperture of 10″.

The visible spectrum was reduced using the software packages MIDAS and IRAF according to the standard procedure (Lazzarin et al. 1995). The wavelength calibration was performed using Helium, HgCd, and Argon lamp spectra. The spectrum was corrected for telluric and solar contribution using the solar analog HD 209847 observed at similar airmass (Table 3).

2.2. Near-infrared observations

The near-infrared observations were carried out by ISAAC in the SW mode (1 to 2.5 microns wavelength range) which is equipped with a Rockwell Hawaii 1024 × 1024 pixel Hg:Cd:Te array. The spectroscopic observations were performed during

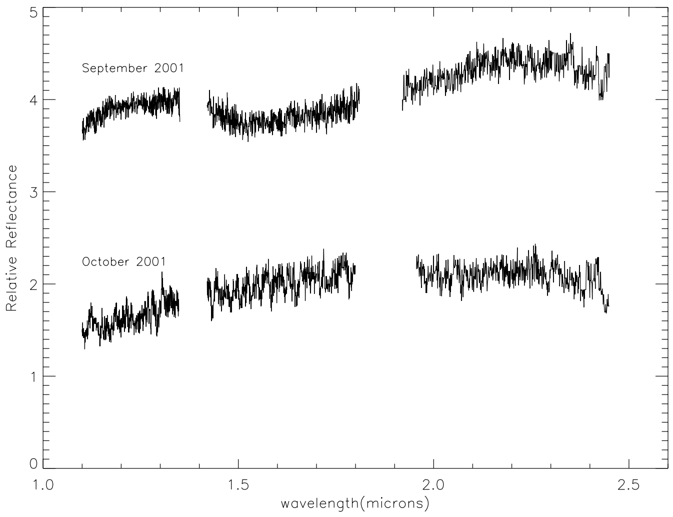

Fig. 1. Spectral reflectance of 2001 PT_{13} obtained in the *J*, *H* and *K* ranges observed in September and October. The September spectrum has been shifted by 2 units for clarity.

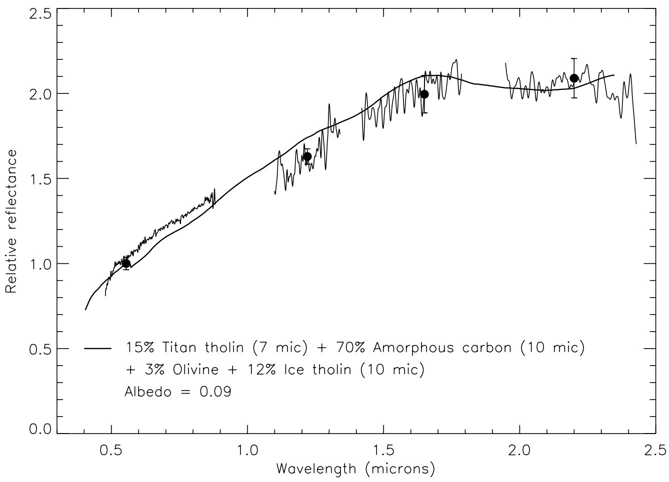

Fig. 2. The October reflectance spectra of 2001 PT_{13} in the *V*, *J*, *H*, and *K* ranges have been adjusted using the photometric *V*, *J*, *H* and *K* colors and have been normalized to 1 at 0.55 microns. The superimposed solid line represents the model. The spectrum has been scaled at 0.55 μm to a geometric albedo of 0.09.

September and October 2001 while the photometry was possible only during the October run (Tables 3 and 4). ISAAC was used in its Low Resolution spectroscopic mode, using the low resolution grating at different orders with different order sorting filters. The details of the ISAAC observations are given in Table 3.

The slit used was 1″ wide, which corresponds to a spectral resolution of about 500. The observations were done by nodding the object along the slit by 10″ between 2 positions A and B. The 2 averaged A and B images in each spectral range (*J*, *H*, and *K*) were subtracted from each other. The A–B and B–A images were flat-fielded, corrected for spatial and spectral distortion and finally combined with a 10″ offset. This procedure allows summing up the signal while providing a double subtraction of the OH sky lines which perfectly subtract out. The three spectral ranges (*J*, *H*, and *K*) which correspond to 1.1−1.4 μm, 1.4−1.8 μm and 1.9−2.5 μm respectively have been observed successively with nearly simultaneous photometric measurement in the *J*, *H* and *K*s filters (centred at 1.25, 1.65, and 2.16 microns). The photometric observations were carried out using the jitter imaging technique. A combined image is generated using the jitter routine from the ECLIPSE package and the data processing routines are described in Romon et al. (2001). IR photometric calibration was performed by the multiple observations of three faint IR standard stars taken from Hunt and Persson catalogs (Hunt et al. 1998 and Persson et al. 1998).

The spectra were extracted from the resulting combined images, and wavelength calibration was performed using xenon-argon lamp spectra. Because of the blending of the OH lines at the spectral resolution used, the wavelength calibration is typically accurate to within one pixel.

The same procedure was used for the calibrators. As calibrators, we used C type asteroids 511 Davida and 70 Panopaea and solar-type stars, Hyades 64, and Hyades 142 (Hardorp 1978) and HD 209847 observed at several airmasses. The spectra of the same star HD 209847 observed during the two runs, show identical behaviours.

The 32532 (2001 PT_{13}) spectra have been divided by the spectra of the solar stars corresponding to the best fit in air-masses (see Table 3). The edges of each spectral region have been cut to avoid low S/N spectral regions. The *J*, *H* and *K* spectra, adjusted by eye, are shown in Fig. 1.

In Fig. 2 are shown together the visible and infrared spectra observed in October. The different spectral ranges have been adjusted using the photometric observations in *V*, *J*, *H*, and *K* obtained during the same run. The photometric values have been transformed in reflectivity using solar values (Hardorp 1980 and Hartmann et al. 1982). To improve the S/N ratio, the resulting spectra (Figs. 2 and 3) were smoothed by gaussian filtering of $\sigma = 5$ pixels, providing a final spectral resolution of 250 in *J*, *H* and *K*.

The obtained colour indexes of 2001 PT_{13} are reported in Table 5.

3. Discussion

32532 (2001 PT_{13}) seems to have a rotation period of 8.3 hr or 8.4 hr (Ortiz et al. 2002; Farnham 2001) with an amplitude of its visible lightcurve of about 0.15 mag. The spectra in the *J*, *H*, and *K* regions obtained during the two runs (Fig. 1) show some differences in their general behaviour, indicating differences in the composition. Both spectra present a decrease beyond 2.3 microns. The two observations have to correspond to different portions of the surface. Unfortunately the rough determination of the rotational period does not allow us to verify this rotational hypothesis.

To investigate the possible composition of the surface of 2001 PT_{13}, we have first considered the spectrum obtained in October 2001 since it has the most completely covered spectral range (from 0.4 to 2.45 microns). We ran a radiative transfer model (Douté & Schmitt 1998) considering simple geographical mixtures of organics (kerogen, tholins, amorphous carbon), minerals (pyroxene, olivine) and ices. Tholins

Table 3. Spectroscopic observations (UT time at start exposure).

Obs data	UT (h:m)	Spectral range (μm)	Ex. Time (min)	Instrument	Airmass object	Solar Analogs	Airmass solar analog
10/Sep./2001	04:52	1.10–1.35	40	ISAAC	1.29–1.47	HD 209847	1.28
10/Sep./2001	03:50	1.42–1.81	50	ISAAC	1.18–1.28	HD 209847	1.17
10/Sep./2001	02:16	1.92–2.45	60	ISAAC	1.20–1.16	HD 209847	1.15
10/Oct./2001	00:48	0.48–0.95	40	FORS1	1.15–1.16	HD 209847	1.18
08/Oct./2001	03:34	1.10–1.35	30	ISAAC	1.40–1.59	Hyades 64	1.36
08/Oct./2001	02:20	1.42–1.80	60	ISAAC	1.19–1.39	Hyades 142	1.33
08/Oct./2001	00:30	1.96–2.45	90	ISAAC	1.17–1.15	HD 209847	1.13

Table 4. Photometric observations and results (UT time at start exposure).

Night	UT	Filters	Exp. Time (s)	Airmass	Seeing	mag
07/Oct./2001	23:57	*J*	120	1.22	1.08	17.52 ± 0.03
08/Oct./2001	00:02	*H*	120	1.20	1.54	17.01 ± 0.05
08/Oct./2001	00:14	*K*s	60	1.19	1.26	16.90 ± 0.04
10/Oct./2001	00:24	*B*	360	1.16	0.81	19.88 ± 0.04
10/Oct./2001	00:31	*V*	180	1.16	0.73	19.13 ± 0.03
10/Oct./2001	00:20	*R*	180	1.16	0.54	18.64 ± 0.03
10/Oct./2001	00:35	*I*	240	1.16	0.58	18.18 ± 0.03

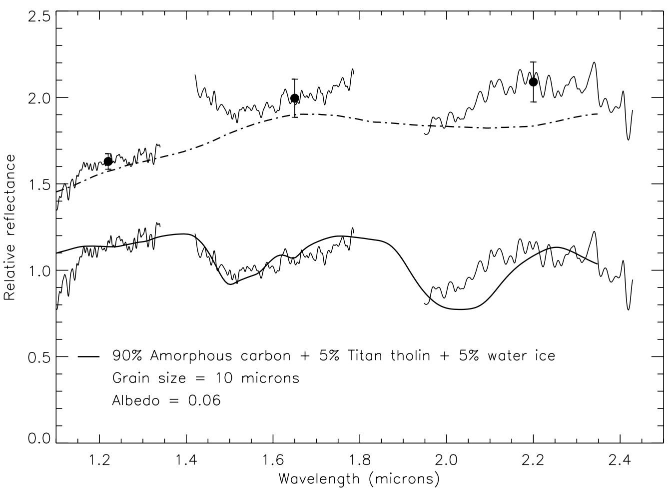

Fig. 3. September spectral reflectance of 2001 PT_{13} in the *J*, *H* and *K* ranges. The upper spectra have been adjusted using the *J*, *H*, *K* photometry (black points) obtained during the October run. The dash-dotted line represents the model reported in Fig. 2. Because the photometry was not available that night, the lower spectra have been adjusted to fit the 1.5 and 2 μm signatures. A new model (continuous line) has been derived. The spectra with the new model have been scaled at 0.55 μm to a geometric albedo of 0.06.

and kerogen generally can reproduce the red slope of the spectrum of many Centaurs and TNOs in the visible range. In particular, Titan tholins (Khare et al. 1984) have been used by Cruikshank et al. (1998) to interpret the spectrum of 5145 Pholus. In the case of 2001 PT_{13}, Titan tholins do not match the red slope of the spectrum, and a better match has been obtained using ice tholins (Khare et al. 1993). Both Titan and ice tholins are synthetic macromolecular compounds, produced from a gaseous mixture of N_2:CH_4 (Titan tholins) or an icy mixture of H_2O:C_2H_6 (ice tholins). The albedo of 2001 PT_{13} is still unknown, so it does not constrain our modelling attempts. However, since most of the Centaurs and TNOs for which the albedo has been measured are dark objects (albedo ≃ 0.04–0.12, Barucci et al. 2002), we assumed that 2001 PT_{13} has a relatively low albedo. Thus we added a low albedo compound (amorphous carbon) to our Titan + ice tholins mixture to account for the low albedo. The amorphous carbon (Zubko et al. 1996) is a dark featureless compound often used for dark surface objects (Barucci et al. 2000; Romon-Martin et al. 2002). The olivine sample (NMNH137044, Clark et al. 1993) has been added to better match the spectrum around 1.1 μm. Finally, to model the October spectrum, we used a mixture of 70% amorphous carbon grains (10 μm size), 15% Titan tholin grains (7 μm size), 12% ice tholin grains (10 μm size), and 3% olivine (grains of large size) (see Fig. 2). This model gives an albedo of 0.09.

The spectrum obtained in September 2001 is different from the one obtained in October (Fig. 1). It shows a clear absorption at 1.5 μm and the reflectivity increase beyond 2 μm typical of water ice absorptions. These features are not present on the spectral observation of October. The model computed for October (Fig. 2) does not at all fit the September spectrum (Fig. 3 upper spectra). Due to the fact that the September night was not photometric, we have no constraint on how to adjust the *J*, *H*, and *K* spectra. Assuming that water ice was responsible for the 1.5 μm absorption and the reflectivity increase between 2 and 2.2 μm, we obtained our best fit with a model consisting of a geographical mixture of amorphous carbon (90%),

Table 5. 32532 (2001 PT13) colour indexes.

$B-V=$	0.75 ± 0.05
$V-R=$	0.49 ± 0.04
$V-I=$	0.95 ± 0.04
$V-J=$	1.61 ± 0.04
$J-H=$	0.51 ± 0.06
$H-K=$	0.11 ± 0.06

Titan tholin (5%), and water ice (5%) with grain sizes of 10 μm and corresponding to an albedo of 0.06 (Fig. 3 lower spectra).

Centaurs have been formed in a zone of the solar system in which the temperature was very low, and ices have to be present on their surfaces. If we consider that Centaurs can evolve into short-period comets, as is the case of Chiron, water ice has to be a major constituent of these bodies. Many hypotheses can explain the non detection of ices in the Centaur spectra. The most common one is the existence of a dark irradiation crust produced by bombardment of high energy charged particles (cosmic and solar). Laboratory simulations investigated possible alteration processes on the surface of this population of objects connected to space weathering (Thompson et al. 1987; Strazzulla 1997 and Strazzulla 1998).

4. Conclusions

The visible and near-infrared photometry and spectroscopy of the Centaur 32532 (2001 PT_{13}) is the first spectroscopic result obtained in the framework of the ESO large program devoted to Centaurs and Trans-Neptunian objects. The main results are i) the computed colour indexes; ii) the evidence for a difference in the near-infrared spectral behaviours obtained during two runs, and iii) detection of absorption features in H and K bands.

Models to investigate the possible surface composition have been performed to interpret the obtained spectra. Two different composition models have been obtained which imply for 2001 PT_{13} an inhomogeneous surface consistent with different composition and/or different surface structures. In one case (September observations) the spectra seem to show the presence of weak signatures of water ice. The lack of accompanying photometry during the September observations prevents us from giving a definitive conclusion. In the October spectrum no obvious water ice signatures appear. Both spectra show a reflectivity decrease beyond 2.3 microns which is common to many TNOs (Brown 2001, private communication), but for which there is no consensus on the interpretation.

Due to the lack of contraints (the albedo value and unambiguous diagnostic signatures), the obtained models give only an indication of the possible materials present on the surface. A precise determination of the rotational period is needed to identify possible patches of different composition on the 2001 PT_{13} surface. Other laboratory experiments are in progress in the framework of our research program to investigate the spectral behaviour of altered (by charged particles bombardment) organic materials and ices. This would help to better understand the composition and the heterogeneity of the 2001 PT_{13} suggested by our spectra.

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