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Water ice on the surface of the large TNO 2004 DW*

S. Fornasier[1], E. Dotto[2], M. A. Barucci[3], and C. Barbieri[1]

[1] Astronomical Department of Padova, Vicolo dell'Osservatorio 2, 35122 Padova, Italy
e-mail: [fornasier;barbieri]@pd.astro.it
[2] INAF - Osservatorio Astronomico di Roma, via Frascati 33, 00040 Monte Porzio Catone (Roma), Italy
e-mail: dotto@mporzio.astro.it
[3] LESIA, Observatoire de Paris, 92195 Meudon Pricipal Cedex, France
e-mail: antonella.barucci@obspm.fr

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Abstract. We have obtained visible and near infrared spectra of the Trans Neptunian object 2004 DW, a few days after its discovery, at the Telescopio Nazionale Galileo (TNG). 2004 DW belongs to the plutino dynamical class and has an estimated diameter of about 1600 km, that makes it the largest known object, except Pluto, in the plutino and classical TNO populations. Our data clearly show the 1.5 and 2 μm bands associated to water ice, while the visible spectrum is nearly neutral and featureless. To interpret the available data we modelled the surface composition of 2004 DW with two different mixtures of organics (Titan tholin and kerogen), amorphous carbon and water ice.

Key words. Kuiper Belt – techniques: spectroscopic

1. Introduction

The Trans Neptunian Objects (TNOs), called also Edgeworth-Kuiper Objects, are presumed to be remnant planetesimals of the solar system nebula. Together with the comet nuclei, they represent the most pristine and thermally unprocessed bodies in the Solar System. Their study can provide important information about the conditions present in the early Solar System.

The knowledge of the physical properties and the surface composition of these objects is still limited (Barucci et al. 2004). After the discovery of 1992 QB1, the known TNO population is rapidly growing thanks to powerful discovery programs: to date more than 800 bodies have been discovered. Nowadays we know five TNOs (in addition to Pluto and Charon) with size bigger or around 1000 km: 20000 Varuna (900 ± 140 km, Jewitt et al. 2001), 55565 2002 AW197 (890 ± 120 km, Margot et al. 2002), 50000 Quaoar (1260 ± 190 km, Brown & Trujillo 2004a) and the recently discovered 2004 DW and 2003 VB12 Sedna, whose diameters are estimated to be around 1600 km. 2004 DW is a slow-moving body discovered on February 17, 2004 by Brown et al. (2004a). It is the brightest known object in the plutino and classical TNO populations after Pluto and Charon, with an absolute magnitude $H = 2.2$ (assuming a slope parameter $G = 0.15$). It belongs to the plutino dynamical class, as it is in the 3:2 resonance with Neptune, with orbital characteristics shown in Table 1.

Table 1. Orbital characteristics of the plutino 2004 DW.

perihelion distance (AU)	30.871
aphelion (AU)	48.075
semimajor axis (AU)	39.473
eccentricity	0.218
inclination (degrees)	20.6
orbital period (years)	248.01

No measurement of the 2004 DW albedo is yet available. The known TNO albedos range from 0.04 to 0.12 and, assuming a mean value of 0.09, the derived diameter of 2004 DW is around 1600^{+800}_{-230} km, larger than those of Charon and 50000 Quaoar. Only 2003 VB12 Sedna, discovered on March 15, 2004 seems to have a similar size, but, with a perihelion of 76 AU, it is an atypical TNO, not a classical nor a scattered object. Sedna is probably a member of a substantial population of bodies trapped between the Kuiper Belt and the Oort Cloud (Brown et al. 2004b).

In this paper we present the results of the visible and near infrared spectroscopic investigation of 2004 DW together with two possible compositional models that match its spectral behaviour.

* Bases on observations obtained at the Telescopio Nazionale Galileo, La Palma, Spain.

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Table 2. Observational circumstances: the starting and final time of observations (date and universal time), the total exposure time, the instrument used, the airmass value at the beginning and at the end of the acquisitions, and the observed solar analog stars with their airmass used to remove the solar contribution.

Object	UT_{start}	UT_{end}	Exp (min.)	INSTR.	Airm.	Solar analog (airm.)
2004 DW	29 Feb. 04, 23:42	1 Mar. 04, 00:39	50	DOLORES	1.18–1.19	La102-1081 (1.17)
2004 DW	1 Mar. 04, 02:15	1 Mar. 04, 03:54	56	NICS	1.40–2.10	La102-1081 (1.46)
2004 DW	1 Mar. 04, 23:56	2 Mar. 04, 01:31	64	NICS	1.18–1.28	mean of La98-978 (1.21)
						and La102-1081 (1.14)

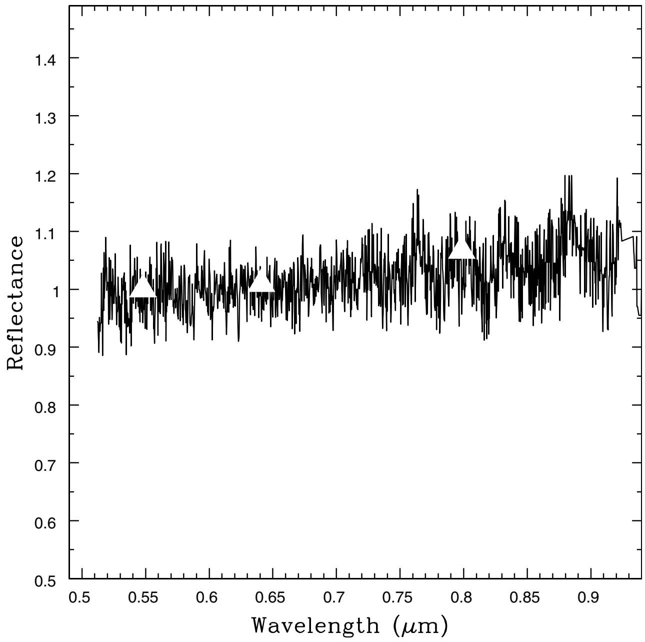

Fig. 1. Visible spectrum of 2004 DW, normalized at 0.55 μm. The $V-R$ and $V-I$ colors derived by Rabinowitz et al. (2004), transformed in spectral reflectance, are also shown on each spectrum as white triangles. The spectrum is in perfect agreement with these color indices.

2. Observations and data reduction

Observations have been made at the 3.56 m Telescopio Nazionale Galileo (TNG) in La Palma, Canary Islands, between February 29 and March 2, 2004. The TNO had an estimated visual magnitude of 19.2 during the observations, as given by the Minor Planet Center ephemeris service. A 1.5 arcsec wide slit, oriented along the parallactic angle to minimize the effect of atmospheric differential refraction, has been used both for the visible and near infrared observations.

For visible spectroscopy we used the DOLORES (Device Optimized for the LOw RESolution) instrument equipped with the low resolution red grism (LR-R) covering the 0.51–0.98 μm range with a spectral dispersion of 2.9 Å/px (`http://www.tng.iac.es`). During the observing run we also acquired bias, flat–field, calibration lamp (Ne-Ar lines) and several solar analog spectra.

The observational circumstances are summarized in Table 2.

The TNO has been identified by taking two images in the V filter separated by about 90 min. In order to make sure we always kept the object in the middle of the slit, the total exposure time was divided into 3 acquisitions of respectively 20, 15 and 15 min. This allowed us to check the asteroid position inside the slit before each acquisition and to reduce the cosmic rays hits on each spectrum. Spectra were reduced using standard data reduction procedures (Fornasier et al. 1999) with the software package Midas. The reflectivity of the TNO was obtained by dividing its total spectrum (mean of the 3 acquisitions) by that of the solar analog star Landolt 102-1081, observed just before the TNO and at very similar airmass.

The reflectance spectrum has been normalized at 0.55 μm and finally smoothed with a median filter technique (Fig. 1).

For the infrared spectroscopic investigation we used the near infrared camera and spectrometer (NICS) equipped with an Amici prism disperser (Oliva 2000). This equipment allows to cover the 0.85–2.40 μm range during a single exposure with a spectral resolution of about 35. The detector is a 1024 × 1024 pixel Rockwell HgCdTe Hawaii array.

The acquisition procedure consisted of a series of 8 cycles of 4 images each (ABBA cycle), for a total exposure time of 64 min. The spectral acquisitions have an exposure time of 120 s each, and were taken in two different positions along the slit, named A and B, offsetting the telescope by 30 arcsec. This technique allows to produce near-simultaneous images for sky subtraction.

A first attempt to get an infrared spectrum was made on March 1st, 2004 just after the visible observations, but this first spectrum, although still useful, has a low signal to noise ratio, because during the exposure time the object reached high airmasses values. Furthermore the solar analog star Landolt 102-1081 was observed just after 2004 DW, but at a different airmass, so the TNO spectrum could be affected by errors in the extinction correction process due to the large variation of the airmass.

We repeated the infrared observations of 2004 DW on the following night, investigating the TNO for about 64 min near its meridian passage. The observing conditions are shown in Table 2. We observed the solar analog stars Landolt 98-978 and Landolt 102-1081 just before and after the TNO investigation.

Data reduction was performed in the standard way for IR observations (Fornasier et al. 2003), except for wavelength calibration where we used a look-up table which is based on the theoretical dispersion predicted by ray-tracing and adjusted to best fit the observed spectra of calibration sources. Finally, the extinction correction and solar removal was obtained by division of the TNO spectrum with that one of the solar analog star.

For the March 1st night we used the Landolt 102-1081 star acquired just after the TNO observations, while for the March 2nd night we used the mean spectrum of the Landolt stars 98-978 and 102-1081 acquired before and after the TNO. To improve the signal to noise ratio, the March 1st spectrum has been smoothed with a gaussian filtering of $\sigma = 3.8$ pixel, providing a final spectral resolution of about 24.

The final infrared spectra are shown in Fig. 2, while in Fig. 3 we represent the full visible and near infrared spectra (infrared spectrum from the March 2nd data), scaled in order to be both normalized at 0.55 μm.

3. Discussion and conclusion

The 2004 DW visible spectrum is represented in Fig. 1: it is practically flat and it does not show any absorption feature, with a behaviour very similar to the typical spectrum of an anhydrous C-type asteroid. We computed the slope of the continuum of the visible spectrum using a standard least square technique for a linear fit of the spectrum in the wavelength range between 0.52 and 0.82 μm. The obtained slope is $1.79 \pm 0.2\%/10^3$ Å. Comparing this value with all the published TNO visible spectral slopes (Fornasier et al. 2004), 2004 DW has one of the smallest values in the TNO population. The spectrum is in good agreement with the $V-R$ (0.37 ± 0.04) and $V-I$ colors (0.76 ± 0.05), transformed into spectral reflectance (Fig. 1), derived by Rabinowitz et al. (2004) on Feb. 26, 2004.

The near-infrared spectra are shown in Fig. 2. The absorption bands around 1.5 and 2.0 μm associated to water ice are evident in the March 2nd spectrum, and seem to be present also on the March 1st spectrum, despite its poor signal to noise ratio and possible errors in the extinction correction procedure.

In order to investigate the possible surface composition of 2004 DW we attempt to reproduce the spectral behaviour by obtaining synthetic spectra of different geographical mixtures (spatially segregated) of minerals, ices and organic compounds at different grain dimensions. In doing this we made the assumption that the TNO has a homogeneous surface composition and/or that our combined visible and near infrared spectra, acquired in two different nights and not simultaneously, are representative of the same reflecting surface. We obtained two models (Fig. 3), with different values of albedo, which well reproduce the V and NIR observed spectra and the signatures at 1.5 and 2 μm. The first one (dashed line) is composed by a geographical mixture of 38% of kerogen (10 μm size), 60% of amorphous carbon (10 μm size), and 2% of water ice (20 μm size), corresponding to an albedo of 0.044 at 0.55 μm. The second one (continuous line) is composed of 4% of Titan tholin (7 μm size), 85% of amorphous carbon (10 μm size), and 11% of water ice (10 μm size), corresponding to an albedo of 0.102 at 0.55 μm. This is only an attempt to analyse the surface composition of this body and the knowledge of the albedo value is necessary to better constrain the obtained compositional models.

Although ices are expected to be a major constituent of TNOs and Centaurs, few spectra of these bodies reveal features attributable to water ice. First evidence of the presence of water ice was detected on the TNO 1996 TO66 infrared spectrum by Brown et al. (1999). The same signatures were found also on the TNOs 20000 Varuna (Licandro et al. 2001), 50000 Quaoar (Brown & Trujillo 2004b) and on the Centaurs 10199 Chariklo (Brown & Koresko 1998; Brown et al. 1998; Dotto et al. 2003a), 2060 Chiron (Luu et al. 2000), 5145 Pholus (Brown 2000), and possibly on one spectrum of 32532 Thereus (Barucci et al. 2002). Features attributable to hydrocarbons have been identified only on 5145 Pholus and 50000 Quaoar: Pholus shows absorption bands possibly attributable to frozen methanol and/or some products of methanol (Cruikshank et al. 1998; Brown 2000), while Quaoar shows distinct absorption features of crystalline water ice, CH_4 and possibly CO_2 (Brown & Trujillo 2004b).

Although 2004 DW is one of the biggest TNOs observed up to now, its spectral behaviour is not peculiar, but it is very similar to that of several other TNOs and Centaurs (Dotto et al. 2003b, and reference therein). Some other components could be present on the surface of this TNO, including both unaltered materials and/or more complex irradiation products as obtained by laboratory experiments by Strazzulla et al. (2003). Further investigations of 2004 DW with an higher resolution and the knowledge of its albedo will help in the fuller comprehension of its spectral properties.

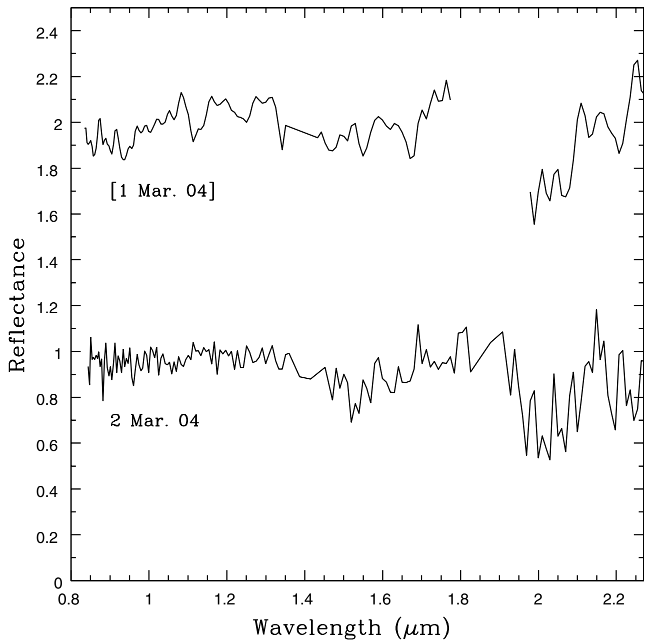

Fig. 2. Infrared spectra of 2004 DW. We show both the spectrum obtained during the 1−2 March night (lower spectrum), and that acquired the 29 February–1 March night (upper spectrum). This last one has been gaussian filtered to improve the signal to noise ratio and could be affected by errors in the extinction correction process, as explained in the text (we also cut the data in the 1.8–2 μm region due to an incomplete removal of the strong telluric water band). The spectra have been normalized at 1.25 μm and the upper one is shifted of 1 for clarity. The water ice absorption bands around 1.5 and 2 μm are clearly visible on the March 2nd spectrum, and seem to be present also on the March 1st one.

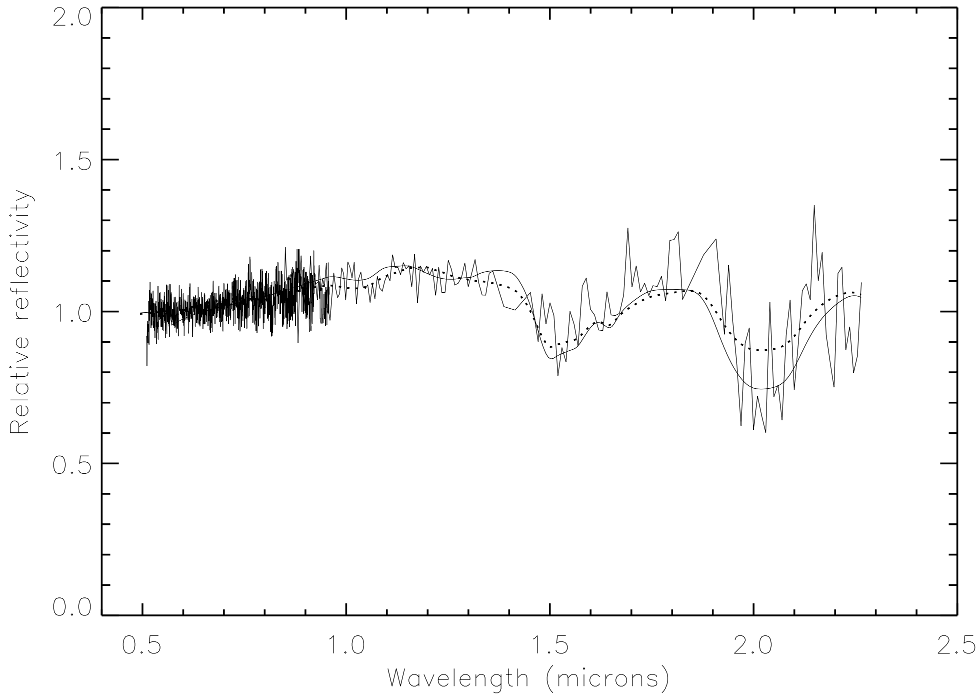

Fig. 3. Visible and near infrared (March 2nd data) spectra of 2004 DW (normalized at 0.55 μm) with superimposed two different compositional models. The dashed line shows the model composed by 38% of kerogen (10 μm size), 60% of amorphous carbon (10 μm size), and 2% of water ice (20 μm size), corresponding to an albedo of 0.044 at 0.55 μm. The continuous line shows the model composed of 4% Titan tholin (7 μm size), 85% of amorphous carbon (10 μm size), and 11% of water ice (10 μm size), corresponding to an albedo of 0.102 at 0.55 μm.

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