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The methane ice rich surface of large TNO 2005 FY_9: a Pluto-twin in the trans-neptunian belt?

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ABSTRACT

Context. The population of known large trans-neptunian objects (TNOs) is growing very fast and the knowledge of their physical properties is a key issue to understand the origin and evolution of the Solar System.
Aims. In this paper we studied the surface composition of the recently discovered TNO 2005 FY_9, one of the largest known TNOs (~0.7 times the diameter of Pluto, i.e. 1600 km, if the albedo is similar, or 3100–1550 km in diameter assuming an albedo range $0.2 < p_V < 0.8$).
Methods. We report visible and near infrared spectra covering the 0.35–2.5 μm spectral range, obtained with the 4.2 m William Herschel Telescope and the Italian 3.58 m Telescopio Nazionale Galileo at "El Roque de los Muchachos" Observatory (La Palma, Spain).
Results. The spectrum of this large TNO is similar to that of Pluto, with an infrared region dominated by very prominent absorptions bands formed in solid CH_4. At wavelengths shorter than 0.6 μm, the spectrum is almost featureless and red. The red color most likely indicates the presence of complex organics, as has been hypothesized for Pluto and many other TNOs. The icy-CH_4 bands in this new giant TNO are significantly stronger than those of Pluto, implying that methane could be even more abundant on its surface. The existence of a volatile such as methane on the surface of 2005 FY_9, likely accompanied by N_2 and CO ices, coupled with its large size, make this Pluto-like TNO an excellent candidate to have an atmosphere comparable to Pluto's.

Key words. minor planets – comets – infrared – trans-neptunian objects

1. Introduction

Identified as the source of the short period comets by Fernández (1980), the trans-neptunian region is populated by icy bodies (TNOs), remnant planetesimals from the early solar system formation stages (Edgeworth 1949; Kuiper 1951). They are probably the most pristine objects in the Solar System. Temperatures in this region (~40 K), are low, so ices trapped at formation should be preserved and can provide key information on the composition and early conditions of the pre-solar nebula. Until recently, only water ice was clearly detected in the spectra of several TNOs, e.g. 1996 TO_{66} (Brown et al. 1999), (20000) Varuna (Licandro et al. 2001), (50000) Quaoar (Jewitt & Luu 2004; Pinilla et al. 2004), (90482) Orcus (Fornasier et al. 2004), 2002 TX_{300} (Licandro et al. 2005). On the other hand, the spectrum of the most prominent member of the trans-neptunian belt, Pluto, is dominated by strong methane ice absorption bands and weak but unambiguous signatures of CO and N_2-ice (e.g. Cruikshank 1998). These bands are also detected in the spectrum of Neptune's satellite Triton (Cruikshank et al. 1993), a possibly captured ex-TNO.

The recent discovery of three very bright TNOs, 2003 EL_{61} (Ortiz et al. 2005), 2003 UB_{313} and 2005 FY_9 (Brown et al. 2005a, 2005b) with $V \sim 17.5$, $V \sim 18.9$ and $V \sim 16.9$ respectively, provide an excellent opportunity to obtain spectra of TNOs with good S/N.

TNO 2005 FY_9 is one of the largest and brightest known objects in the trans-neptunian belt according to its absolute magnitude ($H_V \sim -0.1$). If the surface albedo is similar to that of Pluto, as suggested by the similarity of the spectra presented in this paper, its diameter is about 0.7 times that of Pluto (2350 km), i.e. ~1600 km, larger than Charon (1250 km). In this paper we present visible and near-infrared spectroscopy of 2005 FY_9 and derive mineralogical information from its surface.

2. Observations

We observed 2005 FY_9 on 2005 August 1.87 UT simultaneously with two telescopes at the "Roque de los Muchachos Observatory" (ORM, Canary Islands, Spain), namely the 4.2 m William Herschel (WHT) and the Italian 3.6 m Telescopio Nazionale Galileo (TNG), under photometric conditions. The TNO had heliocentric distance 51.89 AU, geocentric distance 52.56 AU and phase angle 0.8°.

The visible spectrum (0.35–0.98 μm) was obtained using the low resolution gratings (R300B in the blue arm, with a dispersion of 0.86 Å/pixel, and the R158R with a dispersion of 1.63 Å/pixel) of the spectrograph ISIS at WHT, and a 5″ slit width oriented at the parallactic angle to minimize the spectral effects of atmospheric dispersion. The tracking was at the TNO proper motion. Four 300 s spectra were obtained by shifting the object by 10″ in the slit to better correct the fringing. Calibration and extraction of the spectra were done using IRAF and following standard procedures (Massey et al. 1992). The four spectra of the TNO were averaged. The reflectance spectrum was obtained by dividing the spectrum of the TNO by the spectrum of the solar-analogue star BS4486 obtained the same night at a similar airmass just before the TNO spectrum.

The near-infrared spectrum was obtained using the high throughput, low resolution spectroscopic mode of the Near-Infrared Camera and Spectrometer at the TNG, NICS, with an Amici prism disperser. This mode yields a complete 0.8–2.5 μm spectrum. We used a 1.5″ wide slit corresponding to a spectral resolving power $R \sim 34$ along the spectrum. The slit was oriented at the parallactic angle and the tracking was at the TNO proper motion. We used the observing and reduction procedure described by Licandro et al. (2002). The total exposure time is 1080 s. To correct for telluric absorption and to obtain the relative reflectance, the G star Landolt 107-998 (Landolt 1992) was observed just before and after the TNO and was used as a solar analogue. Finally, the near-infrared spectrum was scaled to match the visible spectrum in the 0.80–0.98 μm region. Considering that the seeing was 0.8″, the final resolving power of the spectrum is ∼1000–1200 in the visible and ∼60 in the 1–2.5 μm region.

The final VNIR reflectance spectrum, normalized at 0.6 μm is plotted in Fig. 1. The spectra of Pluto and pure methane ice are also plotted for comparison.

3. Discussion

The similarity between the spectra of Pluto and 2005 FY_9 is striking. All the very prominent absorption bands observed in Pluto's spectrum, which correspond to CH_4 ice bands, are also visible in that of 2005 FY_9. In particular in the visible region (see Fig. 2), almost all the methane ice absorption bands reported by Grundy et al. (2002), even the weaker ones, are detected (see Table 1) and are much deeper than those in Pluto's spectrum. The prominent bands at 0.73 μm and 0.89 μm are ∼6 and ∼3 times deeper respectively, while bands in the near infrared spectrum are <2 times deeper, though it is more difficult to compare at those wavelengths, where our spectral resolution is limited.

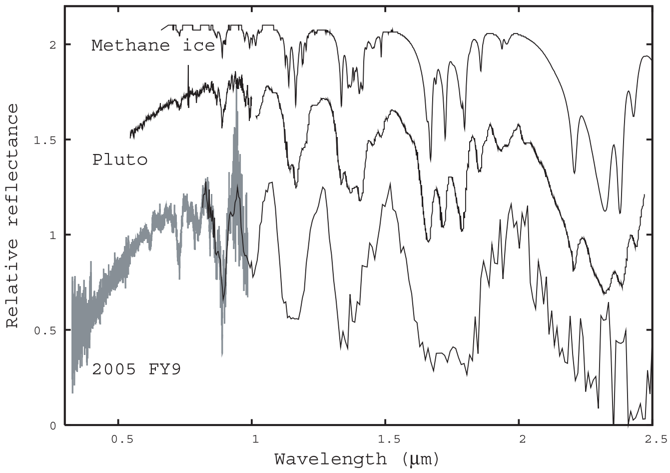

Fig. 1. Visible (grey) and near-infrared (black) reflectance spectra of 2005 FY_9 obtained on August 1st, 2005. The spectrum of Pluto (Grundy & Fink 1996), normalized at 0.6 μm and the spectrum of pure methane ice, both shifted vertically, are plotted for comparison. The spectrum of 2005 FY_9 is very similar to that of Pluto and reveals important features: (1) the slope of the continuum in the visible range is red, indicative of the presence of complex organics; (2) there are several CH_4 ice absorption bands; (3) The methane ice absorption bands in the spectrum of 2005 FY_9 are deeper than the same bands in Pluto's spectrum.

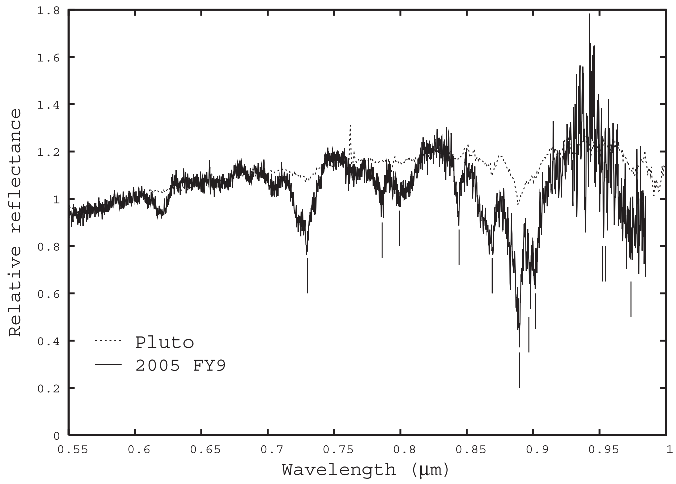

Fig. 2. Reflectance spectrum of 2005 FY_9 in the visible range compared to a reflectance spectrum of Pluto (Grundy & Fink 1996; Brown & Calvin 2000), both normalized at 06 μm. Vertical marks indicate the central position of pure methane ice bands (Grundy et al. 2002). (1) the slope of the continuum in the visible range is red, indicative of the presence of complex organics; (2) there are numerous absorptions bands of CH_4 ice; (3) the methane ice absorption bands in the spectrum of 2005 FY_9 are deeper than the same bands in Pluto's spectrum, at least at shorter wavelengths.

Although uncertainty regarding the absolute albedo of 2005 FY_9 makes quantitative spectral modeling premature, we can already conclude from its deeper CH_4 bands that light reflected from 2005 FY_9 samples larger mean optical path lengths in CH_4 ice than light from Pluto does. Larger grain sizes would accomplish this, as would higher CH_4 concentrations dissolved in nitrogen ice. Broader geographic distribution of CH_4 ice on

Table 1. Position of methane lines. Laboratory data from Grundy et al. (2002), Pluto data (with uncertainties ~10 Å) from Grundy & Fink (1996).

Band	Pure methane (Å)	2005 FY_9 (Å)	Pluto (Å)
$3\nu_1 + 4\nu_4$	7299	7296	7290
$3\nu_3 + 3\nu_4$	7862	7860	–
$3\nu_1 + 3\nu_4$	7993	7888	8015
$\nu_1 + 3\nu_3$	8442	8437	8430
$3\nu_3 + 2\nu_4$	8691	8685	8690
$2\nu_1 + \nu_3 + 2\nu_4$	8897	8891	8885
$2\nu_3 + 4\nu_4$	9019	9015	–

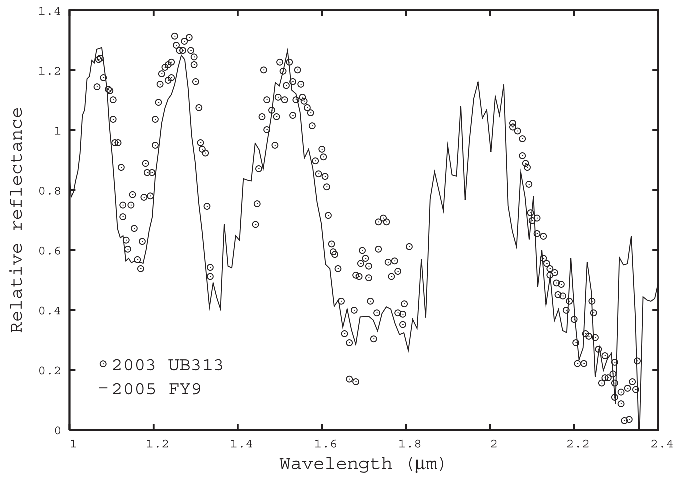

Fig. 3. Reflectance spectrum of 2005 FY_9 in the near-infrared range compared to the reflectance spectrum of TNO 2003 UB_{313} (Brown et al. 2005d), normalized to match that of 2005 FY_9 around 1.6 μm. Notice that, apart from the different resolutions of the spectra, and within the S/N, both look very similar: the large methane ice absorption bands are observed with similar depths, indicating similar compositions.

2005 FY_9 could contribute as well, since Pluto's CH_4 ice is inhomogeneously distributed (Grundy & Buie 2001). We note that the weaker CH_4 bands at shorter wavelengths require especially large path lengths in CH_4 ice, since absorption by those bands is much weaker than the stronger, near-infrared bands, which require relatively little CH_4 to produce deep absorption bands. Consequently, the shorter wavelengths are particularly sensitive to regions having the most abundant CH_4 ice.

The other important characteristic of the spectrum is its colour in the visible region. The red colour is indicative of the presence of a strong ultraviolet absorber. To compare with Pluto we computed the ratio of the reflectance spectrum at 0.825 and 0.590 μm as in Grundy & Fink (1996). The value of this ratio is 1.21, almost equal to that Pluto (1.20). This corresponds to a spectral slope $S' = 8.9\%/1000$ Å, a red colour typical of TNOs. The most accepted hypothesis is that such a red colour is due to complex organics molecules (tholins) formed from simple organics by photolysis (e.g. Khare et al. 1984).

While Pluto's spectrum is dominated by the strong CH_4 absorption bands first observed by Cruikshank et al. (1976), two other volatile ices have since been indisputably detected: CO and N_2 (Owen et al. 1993). The hexagonal β phase of N_2 ice was detected by means of its 2.15 μm absorption band and CO ice was detected by means of a pair of narrow bands at 2.35 and 1.58 μm. Our spectral resolution is much too low to see the CO absorptions. The N_2 band would also be difficult to detect, even if N_2 were a major component of the surface of 2005 FY_9, because the nitrogen absorption has about a factor of a thousand smaller peak absorption coefficient than that of the nearby CH_4 band at 2.2 μm, which dominates that spectral region. We looked for absorptions of solid CO and N_2 in the spectrum of 2005 FY_9 but, unfortunately, the resolution and S/N of our near-infrared spectrum are insufficient to say anything about the absorption bands of either species. It is also possible that surface temperatures on 2005 FY_9 might be below the 36.5 K transition temperature between the warmer β phase of N_2 ice, and the colder, cubic α phase of N_2 ice, which has an extremely narrow 2.15 μm absorption, which would be unresolved in our data (e.g., Grundy et al. 1993). Future, higher spectral resolution observations will put more constraints on the presence of N_2 and CO ice in the surface of 2005 FY_9.

Pluto's CH_4 bands are seen to be partially shifted to shorter wavelengths relative to the wavelengths of pure methane ice absorption bands, indicating that at least some of the methane ice on Pluto's surface is diluted in N_2 (Quirico et al. 1997; Schmitt et al. 1998; Douté et al. 1999). To measure the central wavelength and depth of the methane ice absorption bands is very difficult in our near-infrared spectrum owing to its very low resolution. But our visible spectrum has sufficient S/N and resolution (see Fig. 2). Central wavelengths of the deeper methane ice bands in the visible spectrum of 2005 FY_9 are presented in Table 1. The wavelengths are slightly shorter (~5 Å) than those of pure methane ice, but within the error of our wavelength calibration (~7 Å). A shift of only ~17 Å in the 0.89 μm band is produced in a solid solution containing roughly 20% of methane dissolved in N_2, as observed in Pluto. This shift results from 2 unresolved components: a longer wavelength pure CH_4 absorption and a shorter wavelength diluted CH_4 absorption. Smaller apparent shifts should result from higher CH_4 concentrations. At present, we can not determine conclusively if some of the observed methane ice in 2005 FY_9 is diluted in N_2, but its wavelength suggests it is mostly pure, or at least has a higher concentration than observed for Pluto's near-infrared CH_4 bands (e.g., Douté et al. 1999).

The prominent water ice absorption bands at 1.5 and 2.0 μm are not apparent in the 2005 FY_9 spectrum, just as is true of Pluto (Brown 2002; Grundy & Buie 2002). Water is essentially non-volatile at 40 K. It must be abundant in the interior of TNOs from cosmochemical considerations, and was indeed detected in spectra of several of them. For 2005 FY_9, it would be difficult to detect a small fraction (a few percent) of water ice on its surface since near-infrared water ice absorption bands are masked by the strong methane ice bands in the near-infrared. Much higher S/N spectra and detailed surface scattering models would be needed for a conclusive result, but our spectrum of 2005 FY_9 already excludes the presence of a high abundance of water ice exposed at its surface. We argue that, as is the case for Pluto, the surface of 2005 FY_9 has a mantle of volatile compounds blanketing water ice from the interior.

Considering the similarities in composition and size of Pluto and 2005 FY_9, and considering that Pluto has an atmosphere (e.g., Cruikshank & Silvaggio 1980; Fink et al. 1980; Pasachoff et al. 2005), the possibility arises that 2005 FY_9 also has an atmosphere. According to Elliot & Kern (2003), three conditions must be satisfied for a TNO-like object to have a bound atmosphere: (1) the body must have an inventory of volatiles on its surface that can sublimate; (2) the temperature must lie within the correct range – high enough for adequate vapour pressure, but not so high that the atmosphere would escape into space; (3) the body mass must be sufficient to retain an atmosphere. 2005 FY_9 seems to satisfy all three: volatiles are present at its surface, it orbits in a region slightly farther than Pluto (39–52 AU compared with 30–49 AU for Pluto) so its surface temperatures should be comparable or less than Pluto's, and its size is also similar to that of Pluto. We conclude that 2005 FY_9 is an excellent candidate to have an atmosphere similar to that of Pluto. As in the case of Pluto, the observation of an occultation of a star by 2005 FY_9 could detect this atmosphere.

Finally, Brown et al. 2005d presented a near infrared spectrum of 2003 UB_{313} showing that it also has deep methane ice absorption bands. In fact, the spectra of 2005 FY_9 and 2003 UB_{313} look very similar (3), but 2003 UB_{313} is not as red in the visible (Brown et al. 2005d). The presence of frozen methane on the surfaces of Pluto, Triton, 2005 UB313 and 2005 FY_9 argues that the process suggested by Spencer et al. (1997) in which surface methane is replenished from the interior, may be ubiquitous in large trans-neptunian objects. 2005 FY_9 and 2003 UB_{313} provide an exciting new laboratory for the study of processes considered for Pluto and Triton: volatile mixing and transport; atmospheric freeze-out and escape, ice chemistry, and nitrogen phase transitions.

4. Conclusions

We present a new 0.35–2.5 μm spectrum of the TNO 2005 FY_9. The spectrum is very similar to that of Pluto, with a near-infrared region dominated by prominent CH_4 ice absorptions. At wavelengths <0.6 μm the spectrum is almost featureless and red. The CH_4 ice bands in this new giant TNO are significantly stronger than those of Pluto, implying that methane could be even more abundant on its surface. The red color in the visible, almost the same as Pluto, suggests the presence of complex organics. The spectrum in the near-infrared is also very similar to that of TNO 2003 UB_{313}. The abundance of a volatile material such as methane at the probable surface temperature of 2005 FY_9, possibly accompanied by N_2 and CO, combined with a size comparable to that of Pluto, suggests that this Pluto-twin TNO is an excellent candidate to have a bound atmosphere.

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