Surface Ice Spectroscopy of Pluto, Charon and Triton

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We present new reflectance spectra of Pluto and Triton taken with the ESO adaptive optics instrument NACO at the VLT and covering the wavelength range 1–5 μm. Apart from known and expected absorption bands from methane ice, our data reveal new absorption bands centred around 4.0 μm and 4.6 μm never detected before. The latter absorption could be related to the presence of CO ice at the body surfaces. Charon's spectrum is also measured in the wavelength range 1–4 μm, for the first time simultaneously with, but isolated from, that of Pluto. The non-detection of Pluto's moonlets (unknown at the time of observation) in acquisition images of Pluto-Charon provides a lower limit of 18.8 mag for the *K*-band brightness of Hydra and Nix.

Dwarf planets and New Horizons

Things are changing in the outer Solar System: Pluto got 'degraded' by the IAU from a 'real' planet to a dwarf one. Shortly before this terrestrial decision, NASA launched the New Horizons spacecraft to approach Pluto and Charon in 2015 – and possibly one or two, yet undetected, Kuiper Belt objects thereafter. Also, recently, two new small moons, Nix and Hydra, were discovered around Pluto. Despite all these changes, Pluto and Charon, remain of high scientific interest, in particular since they can be considered – together with Neptune's moon Triton – as the best prototypes for the ice worlds in the outer Solar System and the Kuiper Belt. Best, because these three objects are bright and thus accessible for Earth-based observations not easily possible for other bodies of that kind. Here, we present new IR observations of Pluto, Charon and Triton performed with the VLT in order to characterise the ice content of the surfaces and to search for similarities and differences.

Pluto, Charon and Triton with NACO at the VLT

Scientific aim

The observations of the Pluto-Charon binary and of Triton were obtained with the adaptive optics instrument NACO at the ESO VLT during 3–7 August 2005. For Pluto-Charon the aim was to resolve the binary system and to measure spectra of the two objects, for the first time individually. So far, such type of spectra could only be obtained from disentangling unresolved and occultation (Charon occulted by Pluto) measurements of the system. Moreover, and even more important, we intended to extend the wavelength coverage of the surface spectroscopy beyond *K*-band, i.e. we were aiming for Pluto spectra up to 5 μm and for Charon at least up to 4 μm, with the goal to detect further surface ice absorption bands predicted from models of the available *JHK* spectra and to search for signatures of yet unknown ices. Triton, visible from the VLT at the same time, was a welcome object for comparison, since its *JHK* spectrum is similar to that of Pluto (but different from Charon), and at least as well known as the former. Like Pluto, the 3–5 μm region of Triton is still unexplored for this object, considered to be a Kuiper Belt object captured by Neptune.

Telescope and instrument set-up

NACO at the VLT Unit Telescope 4 (Yepun) was our first choice for this programme since it combines the high spatial resolution of adaptive optics, needed to resolve Pluto-Charon (variable along the orbit from 0.5–0.9″), and at the same time benefits from considerable signal-to-noise improvements for the spectroscopy. Moreover, NACO allowed to cover the full wavelength range from 1–5 μm at once with the intended spectral resolution using the prism L27_P1. Nevertheless, the NACO exposure time calculator indicated that, even with the great advantages of adaptive optics and low-dispersion prism, it would be difficult to measure the signal of Pluto and Triton in *M*-band and of Charon in *L*-band in three nights.

Observing procedure

The Pluto-Charon binary and Triton were used in the visible as the reference sources for the adaptive optics corrections. For Pluto-Charon the NACO slit (width 172 mas) was set along the orbital position angle of the binary, to acquire them both simultaneously. For Triton the slit was placed at the parallactic angle. The acquisition of the targets was performed in *K*-band and a suitable offset correction, depending on the zenith distance, was applied to achieve the optimum slit position of the objects in *L*- and *M*-band (though sacrificing slightly the *JHK* signal – at least for higher airmasses – by slit losses due to wavelength-dependent atmospheric refraction). The usual A-B-B-A nodding (with some jitter) was applied for the observations. In order to remove at once the telluric and solar features from Pluto/Charon and Triton's spectra, observations of the nearby solar analogue star HD 162341, recorded approximately once per 1.5 hour, were performed. In this way every Pluto-Charon and Triton observation had an associated 'before' and 'after' set of calibration star observations, made with similar sky conditions and identical instrument and AO settings.

Data reduction

Besides the usual data reduction for IR spectroscopy, special attention was paid to the wavelength calibration and the spectrum curvature correction of the NACO data. The former applies because no arc lamp spectra for *L*- and *M*-band are available in NACO; hence, atmospheric emission and absorption features were used as wavelength reference instead. The latter results from differential atmospheric refraction over the large wavelength range and was corrected by pixel shifts of the spectra applying the atmospheric refraction formula. Thereafter, we used optimum extraction to improve signal-to-noise ratio over aperture extraction. In order to recover from the unavoidable slit losses in the short wavelength region, we combined the extracted

L- and *M*-band spectra, combined over all nights, with selected object spectra in the *JHK* wavelength region and taken at low airmasses. The extracted spectra were normalised to published values for the albedo at fixed wavelengths and thereafter median averaged. This way we were able to reconstruct global spectra of the three targets – flux permitting – over the full wavelength range from 1–5 μm.

Pluto and Triton spectra from 1 to 5 μm

In Figures 1 and 2 we present the reflectance spectra of Pluto and Triton, obtained with NACO in the 1–5 μm wavelength range at a S/N in *J*-*K* and *L*-band equal to 50 and 11, respectively. For Pluto, it is the first time that the *L*-band is measured without contamination by light from Charon, and for both objects *M*-band spectra were never measured before.

Known compounds

The published spectra of the two objects have established that there is solid CH_4 on Pluto and Triton's surface (Douté et al. 1999; Quirico et al. 1999; Grundy et al. 2002), easily noticed from various absorption features in the *JHKL* bands. This is confirmed – in particular also for *L*-band – by our new NACO results. Indeed, in the range of wavelength 1.0–2.5 μm, the most prominent features evident in Pluto and Triton's spectra are strong CH_4 absorption bands near 1.16, 1.38, 1.66, 1.79, 2.20, 2.31 and 2.37 μm (Figures 1 and 2). Because of the low spectral resolution of the NACO prism, it is not possible to detect in both object spectra the absorption bands of N_2 at 2.148 μm and CO at 2.35 μm already found by Owen et al. (1993) and Cruikshank et al. (1993) for Pluto and Triton, respectively. The low resolution in *JHK* bands also does not allow us to detect CO_2 in Triton's spectrum.

In the range of wavelengths 2.8–4.1 μm, our spectra of Pluto and Triton show strong absorptions near 3.3, 3.5 and 3.8 μm, corresponding to methane's ν_3, $\nu_2 + \nu_4$ and 2 ν_4 vibrational transitions (Grundy et al. 2002; Olkin et al. 2007). It is important to note that the slope of

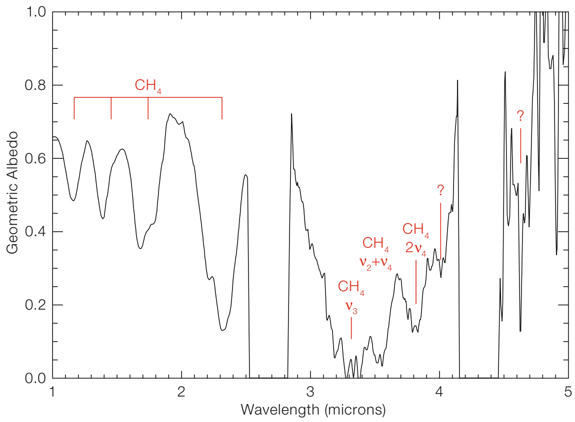

Figure 1: Pluto's spectrum in the range of wavelengths 1–5 μm. The species responsible for the absorption bands detected in our spectrum are marked in the figure. No object flux is measured in the atmospheric absorption bands at 2.5–2.8 and 4.1–4.4 μm.

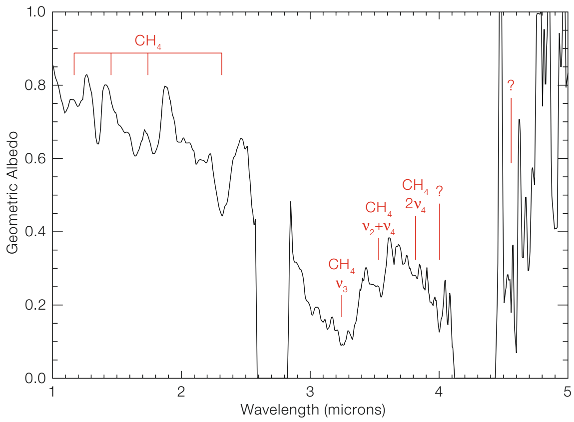

Figure 2: Triton's spectrum in the range of wavelengths 1–5 μm. The species responsible for the absorption bands detected in our spectrum are marked in the figure. No object flux is measured in the atmospheric absorption bands at 2.6–2.8 and 4.1–4.4 μm.

Pluto's spectrum from 2.8 to 3.1 μm, considered to be a diagnostic for the ratio of areas with pure CH_4 ice and CH_4 ice diluted in N_2 (Olkin et al. 2007), is different from the one of Triton. Since the spectrum of pure methane has a steeper slope in this region, this finding suggests that the percentage of diluted methane is higher in Triton than in Pluto. Another difference between Pluto and Triton's spectra is the albedo around the ν_3 band of CH_4 from 3.1 to 3.6 μm. As observed by Olkin et al. (2007), this constrains the fraction of pure N_2 on the surface. Hence, concluding from our NACO spectra, the presence of pure N_2 is greater in Triton than in Pluto.

Unknown features

By modelling Pluto's surface spectrum by geographical mixtures of pure methane, methane diluted in nitrogen and pure nitrogen (Douté et al. 1999), or pure methane, methane diluted in nitrogen and tholin (Olkin et al. 2007), it is not possible to reproduce the absorption band centred around 4.0 μm in our NACO data and indicated in Figure 1 by a question mark. This absorption band is also present in Triton's spectrum (Figure 2). Another question mark can be found in the figures at an absorption band centred around 4.6 μm, visible in both Pluto and Triton's spectra. This signature was found unexpectedly. A first interpretation assigns it to CO ice. In fact, CO ice has a strong absorption band at 4.67 μm (Palumbo and Strazzulla 1993).

Charon's spectrum from 1 to 4 μm

Our NACO spectrum of Charon in the wavelength range between 1 and 4 μm is shown in Figure 3. Charon's spectrum has previously been studied in some detail in the *JHK* wavelength region (Buie and Grundy 2000), but was never measured above 2.5 μm.

As expected, our Charon spectrum is dominated by the 1.5 and 2.0 μm absorption bands of water ice. The spectrum shows the 1.65 μm spectral feature characteristic of crystalline water ice, for the first time identified by Brown and Calvin (2000). Because of the low prism resolution, it is not possible to detect the absorption band at 2.21 μm related to the presence of ammonia hydrate NH_3H_2O, that should exist uniformly distributed on Charon's surface.

A narrow absorption band is found around 3.7 μm, indicated by a question mark in Figure 3. It cannot be reproduced by models of Charon's spectrum with pure H_2O ice darkened by a spectrally neutral continuum absorber (Olkin et al. 2007). Hence, it remains unidentified for the time being.

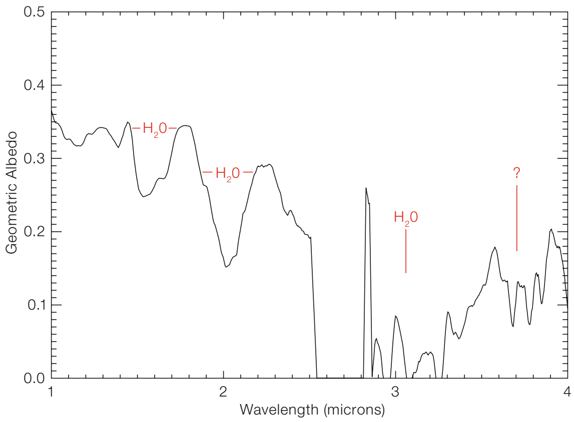

Figure 3: Charon's spectrum in the range of wavelengths 1–4 μm. The species responsible for the absorption bands detected in our NACO spectrum are marked in the figure. No object flux is measured in the atmospheric band between 2.5 and 2.8 μm.

A brief search for Pluto's moonlets

At the time of our NACO observations, Pluto's satellites, Hydra and Nix, had yet to be discovered (Weaver et al. 2006). Although the direct images of the Pluto-Charon system, taken with NACO for the slit acquisition of the binary, were never meant to be searched for the very faint new moonlets, we made an attempt to detect them in our few short (3 sec) exposures (see Figure 4). Unfortunately, we didn't find Pluto's new moons in our frames. Given the limiting magnitude of about 18.8 mag determined for our acquisition images, this detection is not surprising since both objects should have *K*-band magnitudes well beyond 21 mag. Longer integrations would have certainly displayed the moons in the NACO images, but would have resulted in a reduction of exposure time for our prime – and only – programme at that time, the spectral analysis of the surface ices on Pluto, Charon, and Triton.

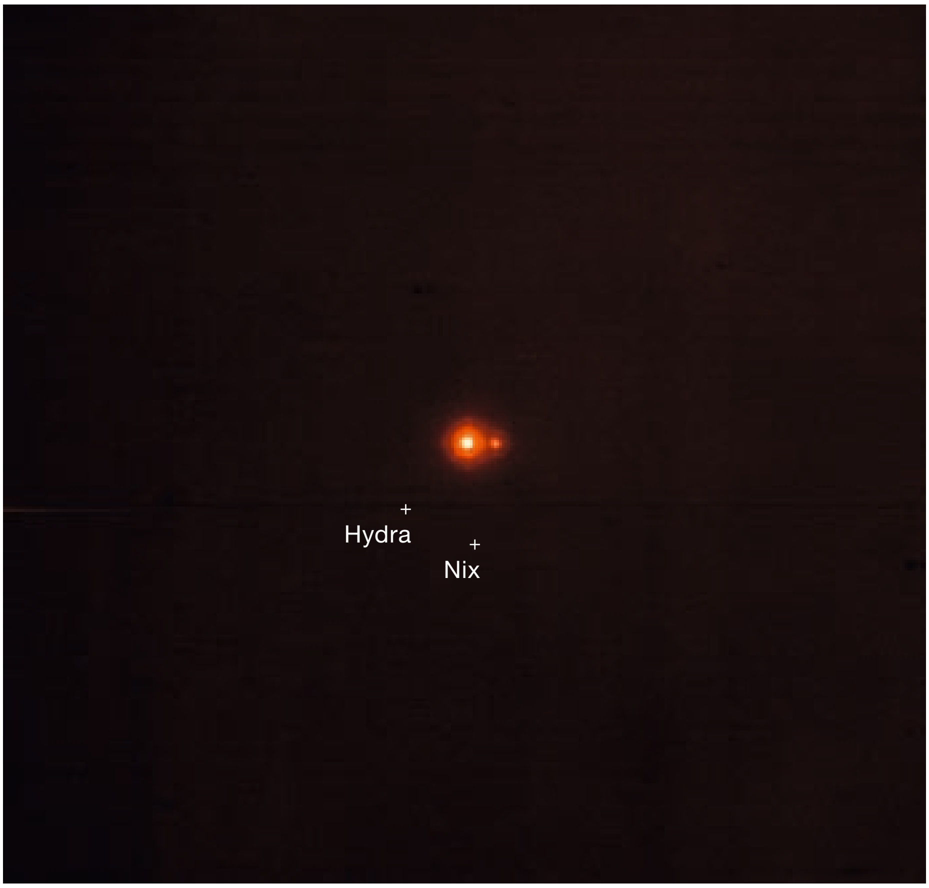

Figure 4: Median average of the slit acquisition images of Pluto and Charon in the night 4 August 2005. The expected positions of the moons Hydra and Nix are indicated by crosses.

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Arrival of the first Japanese ALMA antenna at the Operations Support Facility (OSF) in July 2007.

Photo: F. Mac Auliffe, ESO