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Letter to the Editor

Infrared spectroscopy of the Centaur 8405 Asbolus: first observations at ESO-VLT*

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Abstract. Centaurs constitute a separate population of Solar System objects, with orbits crossing one or more of the giant planets' orbits. They are located on unstable orbits with short lifetimes, and are probably transition objects between Trans-Neptunians and short-period comets. We present near-infrared spectroscopic observations of one of the Centaurs, 1995 GO, now named 8405 Asbolus, carried out at the ESO-Very Large Telescope (Mount Paranal, Chile) in May 1999. Spectra obtained in the J, H, and K bands show a rather featureless behavior with, in particular, no detection of H_2O ice.

Key words: book reviews – book reviews – book reviews – book reviews – book reviews – book reviews

1. Introduction

The Centaurs are minor planets with orbits having semi-major axes between those of Jupiter and Neptune. Their orbits are unstable, with dynamical lifetimes measured in millions of years. Long-term orbital integrations (Stern 1995, Duncan et al. 1995, and Stern & Campins 1996) of the Trans-Neptunians Objects (TNOs) indicate that perturbations by giant planets or mutual collisions can change the orbits in such a way that they become Centaur-like. It is therefore believed that Centaurs originate in the Kuiper Belt. Furthermore, this population can be a source of short period comets (Levison & Duncan 1997).

To date, 17 objects of this particular population have been discovered, following the continuously updated list from the Minor Planet Center (Marsden 2000). Though a strict definition of this class does not exist, Jewitt & Kalas (1998) added to the list of Centaurs as defined in Marsden (2000) two comets: P/Schwassmann-Wachmann 1 and P/Oterma. Jedicke & Herron (1997) estimated that as many as two thousand Centaurs exist with sizes intermediate between comets and 2060 Chiron. This implies that the Centaur population can be as important, or even larger, than the Main Belt asteroid population in the same size range.

Although this new class of objects, the Centaurs, is interesting in its own right, it is also interesting because of its origin in the Kuiper Belt. As Centaurs are currently much closer to the Sun than TNOs, they are brighter than the brightest TNOs and can therefore be more easily studied. However, most of them are still quite faint in absolute terms, so considerable dedication is required to obtain information on their physical properties. Little work has been done so far to reveal their compositions, colors, shapes, and rotational properties. Reviews on the subject can be found in Davies et al. (1998), and Davies (1999). Concerning the surface composition, Luu & Jewitt (1996) were the first to show evidence for a wide dispersion in the colors of the Centaurs, very similar to what is found for TNOs. Barucci et al (1999) observed 5 Centaurs by visible spectroscopy and they also confirmed a diversity among the reflectances of the observed objects. They obtained spectra distributed between very flat for 2060 Chiron and very red for 7066 Nessus, which appears, in the visible region, to be nearly as red as 5145 Pholus, the reddest object in the Solar System so far. They did not find however any correlation between colors and perihelion distance, and there is currently no satisfactory explanation for such a color diversity.

Ices have been identified at the surface of Centaurs. Water ice has been detected on 1997 CU_{26} (now named 10199 Chariklo) (Brown & Koresko 1998, Brown et al 1998, and McBride et al 1999), on 5145 Pholus (Cruikshank et al. 1998), and on 2060 Chiron (Foster et al. 2000, Luu et al. 2000). Methanol ice, or another light hydrocarbon ice, has also been identified on 5145 Pholus (Cruikshank et al. 1998). Chiron is the only object of this group (official list of the Minor Planet Center) which has shown cometary activity (see, e.g., Meech et al. 1990). But other Centaurs, like 8405 Asbolus and 5145 Pholus, that come as close

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* Based on observations carried out at the European Southern Observatory, Paranal, Chile (programme 63.S-0200)

Table 1. Orbital and physical characteristics of 8405 Asbolus

perihelion (AU)	6.8
aphelion (AU)	29.1
eccentricity	0.62
inclination (degrees)	18
orbital period (years)	76.4
diameter (km)	∼ 74
rotation period (hrs)	8.9

to the Sun as 2060 Chiron, or even closer, have not shown any sign of activity.

Since the TNOs represent the most primordial material of our solar system, and since dynamical links between TNOs and Centaurs have been established, we started an observational campaign at the ESO-Very Large Telescope (VLT) in Chile (Mount Paranal) to study the surface composition of these objects by near-infrared spectroscopy. The observations reported here were made during the first observing period available at the VLT with the Antu telescope (the first 8 meter telescope of the VLT built on Mount Paranal). Spectra of one of the brightest Centaurs, 1995 GO, now named 8405 Asbolus, were recorded in the J, K and H spectral ranges with the infrared spectrometer ISAAC. 8405 Asbolus has a highly elliptical orbit with a perihelion inside Saturn's orbit, and an aphelion slightly inside Neptune's orbit. Its main orbital characteristics, size and rotational period are listed in Table 1. The diameter of 8405 Absolus listed in Table 1 has been estimated by Jewitt & Kalas (1998) assuming that its albedo is 0.04, by analogy with 5145 Pholus, 1997 CU_{26}, and cometary nuclei measured albedos (see Davies 2000).

2. Observations and data reduction

The observations were carried out with the Infrared-Cooled grating spectrometer ISAAC (Moorwood et al. 1999) at the first Unit Telescope (Antu) of the ESO-VLT, on 23-24 May 1999. The 1 to 2.5 microns wavelength range camera is equipped with a Rockwell Hawaii 1024 x 1024 pixel Hg:Cd:Te array. The pixel scale is 0.146 arcsec.

The object was observed when it was at an heliocentric distance of 8.94 AU, a geocentric distance of 7.99 AU, and at a phase angle of 2.35 degrees. The estimated apparent visual magnitude at the time of our observations is 18.5. Using the color indexes measured by Davies et al. (1998) the corresponding estimated J, H and K magnitudes are, respectively, 16.8, 16.5 and 16.4.

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 observations are given in Table 2.

A slit 1 arc-second wide was used, which corresponds to a spectral resolution of about 500. The observations were done by nodding the object along the slit by 10 arcsec 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 arcsec offset. This procedure allows to sum the signal up while providing a double subtraction of the OH sky lines which perfectly subtract out.

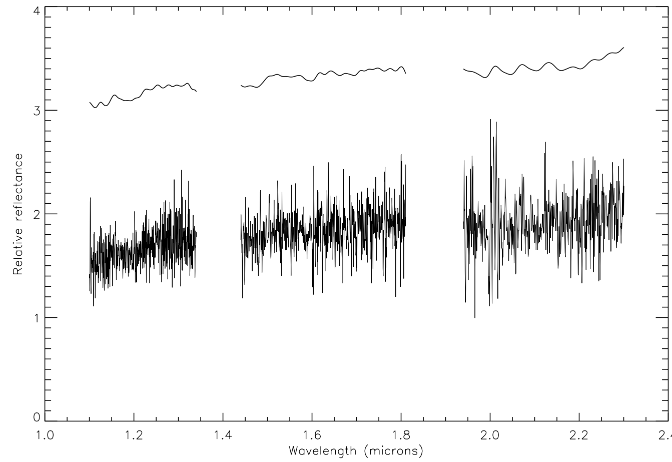

Fig. 1. Spectral reflectance of 8405 Asbolus in the J, H and K ranges. The spectra in the three different bands have been adjusted using the average J, H and K colors of Davies et al. (1998). The spectral reflectances have been arbitrarily normalized to 1 at 0.55 micron. The upper curves correspond to the same spectra as in the lower curve, but smoothed to a spectral resolution of 100 in J and H and 90 in K. The zero level of the spectra in the upper curves has been shifted by 1.5 for clarity.

The spectra were extracted from the resulting combined images, and wavelength calibrated from a sky spectrum obtained from the A images corrected for distortion. 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, which were flat fielded with the same flat fields as the ones used for 8405 Asbolus. As calibrators, we used both a solar-type star (HD 144585; Hardorp 1978), and two C-type asteroids 566 Stereoskopia and 128 Nemesis. Although there are no published near-infrared spectra of these two asteroids, C-type asteroids are known to have, in the near-infrared, a featureless and, in general, flat spectrum, which makes them good solar analogs. In fact, by dividing the two asteroid spectra between themselves, a perfectly flat continuum is obtained in the three spectral ranges, outside regions of strong telluric absorptions. The Asbolus spectra presented in Fig. 1 have been divided by the calibrator ones corresponding to the best fit in air-masses: 566 Stereoskopia in J and H, and HD 144585 in K. The edges of each spectral region have been cut to avoid too low S/N spectral regions. To improve the S/N ratio, the resulting spectra were then smoothed by gaussian filtering of σ = 15 pixels (FWHM = 2.35 σ), providing a final spectral resolution of 100 in J and H and 90 in K. The average S/N ratio after smoothing is between 10 and 20, depending on the wavelength.

In the lack of absolute calibration, the spectra in the different spectral bands have been adjusted using the colors of Asbolus

Table 2. Journal of the observations on 24 May 1999 (UT time at mid exposure).

Spectral range (μm)	Time (UT)	Integration Time (min.)	Slit width (arcsec.)	Dispersion (Å/pixel)	Airmass	Calibrator	Calibrator Airmass
1.1-1.4	05:41	6	1	3.54	1.19-1.21	566	1.22
1.4-1.8	06:06	26	1	4.72	1.22-1.40	566	1.21
1.9-2.5	07:16	64	1	7.09	1.44-2.18	HD144585	1.58

as measured by Davies et al. (1998) over three different nights in March and April 1997, and assuming solar colors V-J=1.07, V-H=1.36 and V-K=1.42 (Degewij et al. 1980) (Fig. 1).

3. Discussion and conclusion

The spectra in the J, H and K regions show a rather featureless behavior. 8405 Asbolus had already been observed in August 1998 by Brown (2000) who obtained at the Keck I telescope a flat spectrum between 1.5 and 2.4 microns at a resolution of about 100. Our observations, which include in addition a spectrum in the J band, confirm the lack of spectral signature observed by Brown (2000). No obvious feature is detected, in particular no absorption due to water ice (bands at 1.5 and 2 μm). Since we may have been looking at a different region of 8405 Asbolus, and since our spectra have a higher S/N ratio, the observations reported here provide additional support for the lack of detectable water ice on the surface of this object. If water ice had a 2-micron absorption as deep as those found in 1997 CU_{26} spectra (Brown et al. 1998), or in 2060 Chiron spectra (Luu et al. 2000), which are about 10 $\%$ deep, we would have detected it.

On Fig. 2, we show a composite spectrum that includes the spectrum obtained in the visible in March 1998 with the ESO-NTT by Barucci et al. (1999). One should note that, since the visible and near infrared data were obtained at different times, they may not correspond to the same area on the Centaur 8405 Asbolus, and therefore this composite spectrum should be used with some caution. This is also the case for the near-infrared colors that were used for the normalization in the J, H and K windows. On Fig. 2 are also shown data corresponding to average V-R and V-I colors as measured by Davies et al. (1998) in May 5-8, 1997, and assuming solar colors of V-R=0.36 and V-I=0.71 as in Davies et al., that indicate a surface slightly "bluer" than observed by Barucci et al. (1999).

The spectrum of 8405 Asbolus, with a slope of $17\%/10^3$Å in the visible range (up to 7500 Å) as measured by Barucci et al. (1999), has a general shape very similar to that of the reddest D-type asteroids (Lazzarin et al. 1995).

As a first check of the possible materials contributing to the spectrum of 8405 Asbolus, we ran a radiative transfer model (Douté & Schmitt 1998) considering a simple geographical distribution of Titan tholins (Khare et al. 1984) - these complex organic solids have been included in models of the surface of 5145 Pholus to account for the steep red slope of the spectrum from 0.4 to 1 micron (see, e.g., Cruikshank et al. 1998) - and amorphous carbon (Zubko et al. 1996).

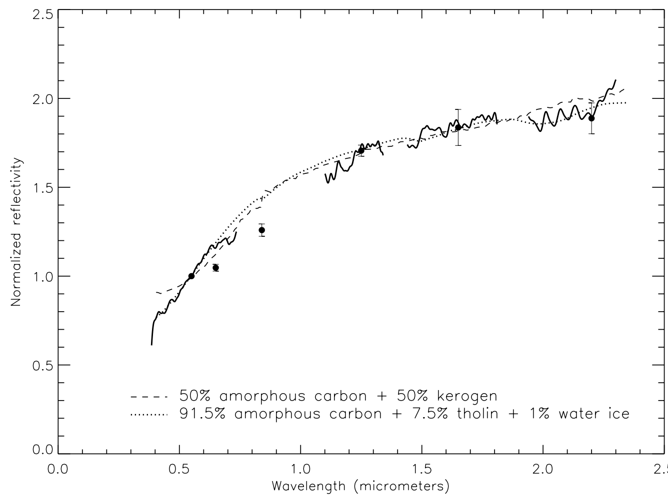

Fig. 2. A composite spectrum of 8405 Asbolus that includes visible data from 1998 by Barucci et al. (1999), and the near-infrared data reported in this paper. As on Fig. 1, the spectra in the J, H and K bands have been adjusted using the average V-J, V-H and V-K colors of Davies et al. (1998). The R and I mean relative reflectances (normalized to 1 at V) of Davies et al. are also shown, as well as the error bars on all Davies et al. (1998) reflectances. Two different models with spatial mixtures are presented. The albedo at 0.55 μm is 0.025 for the carbon+kerogen model, and 0.055 for the carbon+tholin+water ice model. Grain sizes are: 0.1 μm for amorphous carbon, 0.1 μm for tholins and 10 μm for water ice.

The spectrum of 8405 Asbolus was scaled to a geometric albedo at 0.55 micron as close as possible to the value of 0.04 (5145 Pholus albedo: 0.04$\pm$0.03 and 1997 CU_{26} albedo: 0.045$\pm$0.01; see Davies 2000 and Jewitt & Kalas 1998). The best overal fit was obtained with most of the surface covered by sub-micron amorphous carbon grains and the remaining by tholins, and an albedo of 0.04 at 0.55 μm. Tholins allow to reproduce the visible red slope, and amorphous carbon (a dark spectrally featureless material often included in models of dark solar system objects) provides the low albedo and the slight infrared slope.

Kerogen-like organic compounds are plausible constituents of the surface of D-type asteroids (see e.g. Gradie & Veverka 1980). We therefore also considered this kind of material. Some type of kerogens (see Fig. 8 from Cruikshank 1987) can possibly replace the Titan tholins in our models as their spectra display similar red slopes in the visible. Furthermore, they have no absorptions in the near infrared. Due to the much smaller albedo of the kerogens, less amorphous carbon will be needed. Using the laboratory data from Clark published in Cruikshank (1987), we found that, although a combination of 50 % of this type of kerogen and 50 % of amorphous carbon can reproduce the overall shape of the spectrum (Fig. 2), the fit with the spectrum of 8405 Asbolus is not as good below 0.5 μm, and the albedo is only 0.025 at 0.55 μm.

To investigate the limits on the water ice abundance that can be derived from the spectrum, we added a small area of pure water ice at 130 K (Grundy & Schmitt 1998), the expected surface temperature around 9 AU. We found that, in the case of our tholins plus amorphous carbon areal mixture, no more than a few percents of the surface (depending on the grain size) can be covered with pure water ice in order to keep the strong 2-micron ice band within the noise level in the K region (Fig. 2). In the case of the kerogen plus amorphous carbon mixture, no good fit could be obtained when water ice was included.

Different surface representations, in particular intimate mixtures, need to be investigated to better evaluate the materials present, their mode of coexistence and their relative abundances.

8405 Asbolus has orbital characteristics in common with those of the Centaurs 2060 Chiron (perih.=8.4, aph.=18.8), 1997 CU_{26} (perih.=13.1, aph.= 18.4) and 5145 Pholus (perih.=8.7, aph.=31.8). Pholus is however much redder than 8405 Asbolus, which suggests different surface properties. 8405 Asbolus is only slightly redder than 2060 Chiron (Barucci et al. 1999, Davies et al. 1998), but it does not show any sign of activity. The colors of 8405 Asbolus are, in fact, more comparable to those of the Centaur 1997 CU_{26}. However, H_2O ice is clearly detected on 1997 CU_{26}, 2060 Chiron and 5145 Pholus, but not on 8405 Asbolus. The presence or absence of detectable H_2O ice at the surface of Centaurs (as well as the colors of the objects) therefore does not seem to be merely related to the orbital characteristics of the objects.

Luu et al. (2000) have suggested that water ice is common on the surface of Centaurs and that water ice detection is directly connected to cometary-like activity (with water ice detected only when there is no activity). Indeed, water ice was not seen on 2060 Chiron in 1993 (Luu et al. 1994) at a time when its activity was very high. It has been seen on this body only since 1996 (Luu et al. 2000, and Foster et al. 2000), during a period of low activity. However, our observations of 8405 Asbolus do not support this, as the absence of detectable water ice on this body would imply that it is currently active, which has not been demonstrated so far.

Higher signal-to-noise observations, and observations made a few hours apart so that different areas on 8405 Asbolus can be studied, would be very useful to confirm or reject the lack of water ice signatures.

8405 Asbolus will pass through perihelion in 2002, and we are planning to observe it intensively with different techniques to detect any possible activity from that time on.

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