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Letter to the Editor

Near-infrared spectroscopy of the nucleus of comet 124P/Mrkos

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Abstract. We report near-infrared (0.9–2.3 μm) spectral observations of the bare nucleus of comet 124P/Mrkos taken on two different nights using the Near Infrared Camera Spectrometer (NICS) attached to the 3.56 m Telescopio Nazionale Galileo (TNG). Both spectra are very similar, featureless and slightly redder than the Sun, resembling the spectrum of a D type asteroid. The spectrum and the low activity level of the nucleus of 124P suggest that it is covered by a large insulating dust mantle.

Key words. minor planets – comets – infrared

1. Introduction

Comet nuclei and other related icy minor planets like the trans-neptunian objects (TNOs) and Centaurs are remnant planetesimals from the early solar system formation stages. They probably have the giant planet region and the Edgeworth-Kuiper belt as a common origin and contain some of the least modified materials remaining from the protosolar nebula. The study of their surface properties is very important from a cosmogonical point of view (Licandro et al. 2002b; Campins & Fernandez 2002), as it could provide important clues to understand the conditions existing at the early stages of the solar system formation. This study also provides information on their composition, on the processes affecting them, and on the conditions prevailing in the regions of the solar system that they occupy.

In recent years the interest on the study of the surface properties of TNOs and Centaurs has grown very fast and it has prompted several groups to develop spectrophotometric and spectroscopic programs in the visible and near-infrared region. Nowadays, there is a large amount of data on colors and spectra of TNOs and Centaurs, but there is relatively little information on colors and spectra of comet nuclei, making a comparison between these three different but related populations very difficult (see Hainaut & Delsanti 2002; Jewitt 2002; Campins & Fernandez 2002). This comparison is of great interest as Jupiter family (JF) comets are the best suited primitive bodies for "in situ" studies by spacecraft and they can also be studied when active close to the Sun.

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Furthermore, Fernandez et al. (2001), based on albedo observations, estimate that about 5–10% of the Near Earth objects (NEOs) have a cometary origin. Fernández et al. (2002) also study the dynamical evolution which would transport dead comets to the NEOs population. To determine the contribution of comet nuclei to the NEOs population it is very important to compare the surface properties of NEOs in cometary orbits with comet nuclei, and again, the lack of knowledge about the surface properties of the JF comet nuclei is a serious shortcoming. JF comet nuclei are very difficult to observe, they are very small (Fernández et al. 1999), and they are usually embedded in a much brighter coma. To characterize the "bare" nucleus, comets should be observed at large heliocentric distances (typically $r > 4$ AU) when most objects are inactive, but even at such distances some comets present coma (Licandro et al. 2000). Also comet nuclei at $r > 4$ AU are very faint ($V > 20$) thus with the current instruments we are constrained to observe the largest low activity comets as close to the Earth as possible.

For all these reasons, we started an observational program to obtain visible and near-infrared spectra of a significant number of JF comets and related icy minor planets (Licandro et al. 2002b). Near-infrared spectroscopy is a powerful means to remotely determine the components on the surface of the outer solar system objects (e.g. Brown & Cruikshank 1997). In this paper we present the first results on near-infrared spectroscopy of comet 124P/Mrkos.

Comet 124P/Mrkos is a short-period Jupiter-family comet discovered photographically by Antonin Mrkos in March of 1991 (Mrkos 1991). First reported as asteroidal, later observations showed the object to be diffuse and a comet. Shortly after discovery, the comet was estimated at $V \sim 14$ mag and slowly

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faded over the next few months. The nearly four month observational arc allowed Mrkos to be recovered independently by Hergenrother & Offutt (1995). The comet passed perihelion on its third recorded apparition in late July of 2002. The present orbit is determined to have a period of 5.74 years, $q = 1.467$ AU, $a = 3.208$ AU, $e = 0.543$, and $i = 31.35$ deg (Marsden & Williams 2001). Numerical integrations show that Mrkos is currently librating about the 2/1 resonance with Jupiter (Carusi et al. 1995).

2. Observations

We have obtained low resolution spectra of 124P/Mrkos on April 5.9 UT at heliocentric and geocentric distances $r = 1.85$ and $\Delta = 1.89$ AU respectively, and on April 26.9 UT, 2002, at $r = 1.73$ and $\Delta = 1.94$ AU, with the 3.56 m Telescopio Nazionale Galileo (TNG), using NICS, the near-infrared camera and spectrometer (see Baffa et al. 2001). Both nights were photometric and with very stable seeing conditions. Among the imaging and spectroscopic observing modes offered by NICS offers is a unique, high throughput, low resolution spectroscopic mode with an Amici prism disperser (Oliva 2000), which yields a complete 0.9–2.4 μm spectrum in one shot. A 1.5″ width slit, corresponding to a spectral resolving power $R \simeq 34$ and quasi-constant along the spectrum, was used. The low resolution together with the high efficiency of the Amici prism (about 90% in this spectral range) allowed us to obtain spectra of faint objects like comet nuclei, Centaurs and TNOs with a four meter class telescope (Licandro et al. 2001; Licandro et al. 2002a; Licandro et al. 2002b), and with the advantage of having the whole spectral range measured simultaneously.

The identification of the comet was done by taking series of images through the J_s filter ($\lambda_{cent} = 1.25$ μm), and by comparing them. The object was identified as a moving object at the predicted position and with the predicted motion. The combined images (see Fig. 1) do not show any evidence of coma activity. Also the FWHM of the comet images was the same of that for the stars during the same night (1.0″), indicating that any comet activity, if existing, should be very low, and most of the light came from the comet nucleus.

The slit was oriented in the paralactic angle (the position angle for which the slit is perpendicular to the horizon) to take care on the differential atmospheric refraction, and the tracking was at the comet's motion. The acquisition consisted of a series of 3 images of 60 s exposure time in one position (position *A*) of the slit and then offsetting the telescope by 15″ in the direction of the slit (position *B*). This process was repeated and a number of *ABBA* cycles were acquired. The total exposure time was 2520 s both days. The reduction and calibration of the spectra was done as in Licandro et al. (2001).

To correct for telluric absorption and to obtain the relative reflectance, the G stars Land (SA) 110-361, Land (SA) 107-998, and Land (SA) 98-978 (Landolt 1992), which have visible colors very similar to that of the Sun, were observed during the same night and at a similar airmass as the comet. These stars were observed in previous nights and compared to the spectrum of the solar analogue P330E (Colina & Bohlin 1997) also observed by us. The G stars and the solar analogue spectra showed similar spectra in the infrared region, therefore we used the G stars as solar analogs. The spectrum of the comet was divided by the mean spectrum of the solar analogue stars, and then normalized to unity at 1.6 μm, thus obtaining the relative reflectance plotted in Fig. 2. The telluric water absorptions is very strong and varies between the comet spectra and the standard stars spectra, introducing false spectral features in the 1.35–1.45 and 1.80–1.95 μm spectral regions. To avoid erroneous conclusions, these spectral regions are not included in the spectra and not considered for further studies.

3. Discussion

Comet 124P/Mrkos did not show signs of coma activity during our observations. Also CCD observations near the time of ours (Hergenrother, personal communication) shows a comet with stellar appearance and nuclear brightness close to the faintest previously reported (see Tancredi et al. 2000). Thus the spectra presented in this paper, together with the spectrum of 28P/Neujmin 1 published by Licandro et al. (2002b) are the first published near-infrared spectra of bare cometary nuclei.

Both spectra of 124P/Mrkos shown in Fig. 2 (*upper plot*) are very similar, featureless withing the errors and slightly redder than the Sun. The spectral slope (S' in %/1000 Å) is 2 ± 1 on April 5 and 4 ± 1 on April 26. This difference is only marginally significant, but could also be due to a real rotational surface variation. Unfortunately the rotation period of 124P/Mrkos is already unknown and we can not determine if the observations were done in similar rotational phases. Averaging both spectra we obtained the spectrum shown in Fig. 2 (*lower plot*). The spectrum is featureless and with a slope $S' = 3 \pm 1$%/1000 Å very similar to our spectrum of 28P/Neujmin 1 (Licandro et al. 2002b), and similar to the typical spectra of D type asteroids which populate mostly the outer edges of the main belt, featureless and with $S' \sim 3$ (Licandro & Gil-Hutton in preparation).

Water ice is the most abundant component of cometary nuclei, but we do not detect any signature of the water ice absorptions at 1.5 and 2.0 μm in the spectrum of the surface of the nucleus of 124P/Mrkos. Also at the observed heliocentric distances, smaller than 2 AU, we do not detect any cometary activity which is an indication that 124P/Mrkos is a very low activity comet. This is also supported by the behavior of its reported nuclear magnitudes shown in the catalog of JF comet nuclear magnitudes by Tancredi et al. (2000) and in its revised version (Tancredi et al. in preparation). Similar values for the nuclear magnitudes are reported at heliocentric distances ranging from the aphelion to close to perihelion. If we consider its orbit, 124P/Mrkos is currently librating about the 2/1 resonance with Jupiter in a high inclinated orbit. This protects it from deep encounters with Jupiter, thus 124P/Mrkos is moving in a very stable orbit. We tentatively conclude that the nucleus of 124P is highly evolved, and probably has a large insulating dust mantle that prevents its icy components from sublimation.

The slightly red spectra of 124P/Mrkos and 28P/Neujmin 1 are consistent with the color distribution of comet nuclei by

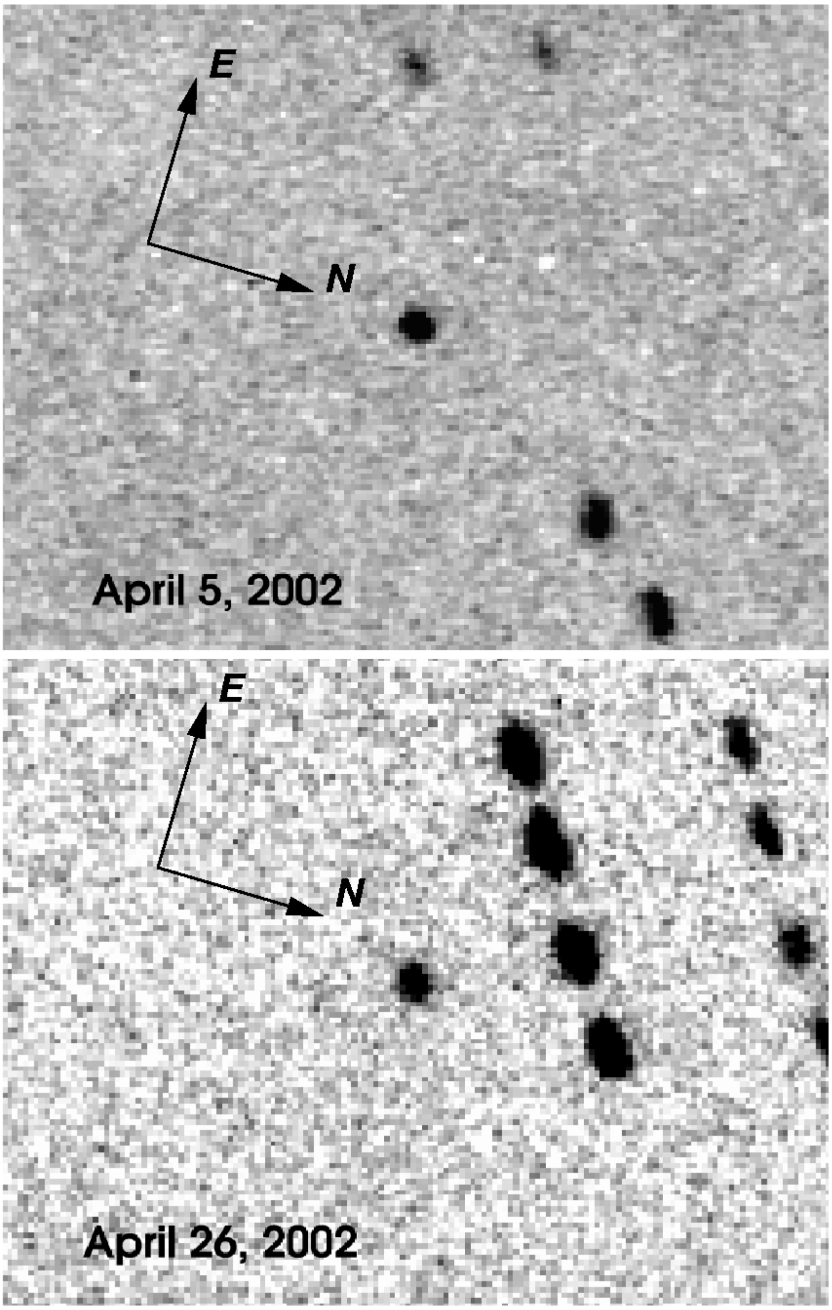

Fig. 1. Images of 124P/Mrkos obtained immediately before the spectra during the two nights. Note that no evident coma is visible in either image. The image size is $38 \times 30''$.

Hainaut & Delsanti (2002) and Jewitt (2002). Compared with the spectra of TNOs and Centaurs that present a large scatter (from neutral to very red objects) in their spectral slopes (see e.g. Licandro et al. 2001, 2002a), it seems that there is no "ultra-red" matter (Jewitt 2002) in the surface of JF comet nuclei. This is probably due to the different resurfacing processes that affect TNOs and Centaurs, and JF comet nucleus. The very red color of some TNOs and Centaurs is probably due to an evolved surface which is the result of long term irradiation by solar photons, solar wind, and galactic cosmic-rays, that results in the selective loss of hydrogen and the formation of an "irradiation mantle" of carbon residues (Moore et al. 1983; Johnson et al. 1984; Strazzulla & Johnson 1991; Gil-Hutton 2002). This process makes that an initially neutral color and high albedo ice turn reddish. On the other hand, the resurfacing due to sublimation that produce the dust mantles of comets, seems to produce slightly red surfaces.

Finally, low resolution spectroscopy in the whole 0.9–2.4 μm range of a significant number of comet nuclei is crucial for the understanding of their surface properties, the physical processes that control their evolution, and the differences among them and other related icy minor planet populations like TNOs and Centaurs (Campins & Fernandez 2002).

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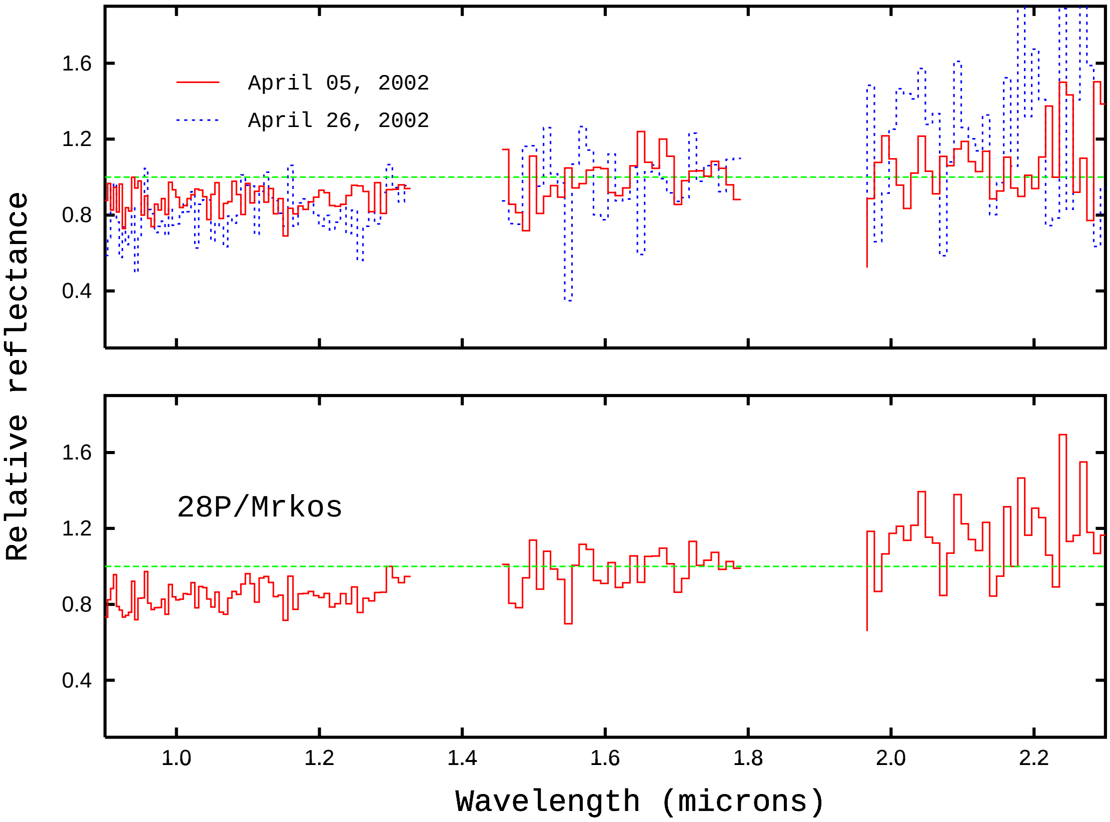

Fig. 2. *Upper plot*: reflectance spectra of 124P/Mrkos obtained in two different nights, April 5.9 UT and April 26.9 UT, 2002. The spectra have been normalized at 1.6 μm. Note that both spectra are very similar, featureless, and correspond to an object with a surface slightly redder than the Sun. *Lower plot*: Average reflectance spectrum of 124P/Mrkos.

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