The near-infrared spectrum of Mrk 1239: direct evidence of the dusty torus?

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ABSTRACT

We report 0.8–4.5 μm SpeX spectroscopy of the narrow-line Seyfert 1 galaxy Mrk 1239. The spectrum is outstanding because the nuclear continuum emission in the near-infrared is dominated by a strong bump of emission peaking at 2.2 μm, with a strength not reported before in an AGN. A comparison of the Mrk 1239 spectrum to that of Ark 564 allowed us to conclude that the continuum is strongly reddened by E(B-V)=0.54. The excess of emission, confirmed by aperture photometry and additional NIR spectroscopy, follows a simple blackbody curve at T~1200 K. This suggest that we may be observing direct evidence of dust heated near to the sublimation temperature, likely produced by the putative torus of the unification model. Although other alternatives are also plausible, the lack of star formation, the strong polarization and low extinction derived for the emission lines support the scenario where the hot dust is located between the narrow line region and the broad line region.

Key words: galaxies:Seyfert – galaxies:individual:Mrk 1239 – galaxies:active – galaxies:nuclei

1 INTRODUCTION

Unified schemes of active galactic nuclei (AGN) invoke the presence of an obscuring dusty torus around the central engine, giving rise to type 1 objects for for pole-on viewing and type 2 objects in edges-on sources. This obscuring structure would also absorb a significant fraction of the optical/UV/X-ray continuum of the central source and should radiate back this energy at IR wavelengths. In fact, dust reprocessing is regarded as the most likely source of the strong near- and mid-infrared (NIR and MIR, respectively) continuum emission in radio-quiet quasars and Seyfert galaxies. Observational evidence favoring models in which the IR continuum between 1 and 10 μm is predominantly or entirely dominated by emission from heated dust is abundant (Edelson & Malkan 1986, Barvainis 1987, Alonso-Herrero et al. 2003). Indeed, evidence of the presence of hot dust near the sublimation temperature in Seyfert 1 galaxies comes from the observation of a peak of emission with central wavelength between 2.2–3.5 μm found from JHKL and L’ photometry (Glass 1992, Marco & Alloin 1998, 2000) in a few objects. Moreover, very recently, Rodríguez-Ardila et al. (2003) found in the inner 250 pc of Mrk 766, a narrow-line Seyfert 1 galaxy, this same excess of emission by means of NIR spectroscopy. They were able to determine accurately the form of the NIR bump, confirming that it follows a simple blackbody function at T=1200 K. They found that the host dust emission accounted for up to 28% of the total NIR continuum flux in that object.

From above, the growing observational evidence of NIR thermal emission at temperatures close to the sublimation temperature of graphite grains in Seyfert 1 galaxies strongly supports the unified models for AGNs. Meanwhile, additional evidence is needed and many open questions have to be answered. In particular, it is necessary to investigate if the thermal emission could be related to a compact dust/molecular thick torus like the ones in the unified models of Pier & Krolik (1992) and Efstathiou & Rowan-Robinson (1995), for instance, or if it results from emission by hot dust (T>900 K) mixed with gas in the NLR/BLR interface region, shielded from the intense UV radiation field (Marco & Alloin 2000).

Here, we contribute to this discussion by presenting the most outstanding evidence of a NIR bump reported to date. It corresponds to the one displayed by Mrk 1239, a compact galaxy, classified as narrow-line Seyfert 1 (NLS1) by Osterbrock & Pogge (1985). Data collected over the past years point out that Mrk 1239 is indeed dusty. Goodrich (1988), for instance, reports that it is one of the three galaxies that display the largest percentage of polarization, both in the line and continuum, in the sample of 18 NLS1 he studied. Smith et al. (2004) modeled the polarization nature of this object and found that it was one of the rare cases of Seyfert 1 galaxies that appear to be dominated by scattering in an extended region along the poles of the torus. According to their results, the line-of-sight to the nucleus would pass through the relatively tenous upper layers of the torus, extinguishing the continuum and BLR emission.
This radiation, would be polarized further off by the dust located above or below the torus.

X-rays observations also confirm the dusty nature of Mrk 1239. XMM-Newton EPIC PN data suggest two light paths between the continuum source and the observer, one indirect scattered one, which is less absorbed, and a highly absorbed direct light path, in agreement to the wavelength-dependent degree of polarization in the optical/UV. Moreover, Mrk 1239 is classified as a 60 μm peaker (Heisler & De Robertis 1999) because of its “warm” far-infrared colours and spectral energy distribution peaking near 60 μm. They attributed these properties to dust-obscured active galactic nuclei (Keel et al. 1994; Hes et al. 1995), the obscuring material likely associated to the putative torus of the unified model.

This letter is organized as follows. In Section 2 we describe the observations, data reduction and resulting spectrum. Section 3 determines the internal reddening affecting the nuclear spectrum of Mrk 1239 and compares the observed NIR SED with that of Ark 564. It also analyzes the different components that contribute to the observed continuum. Section 4 examines the hot dust hypothesis for Mrk 1239 in the light of the strong thermal NIR excess of emission detected. Conclusions are in Section 5. Throughout this work we adopt a Hubble constant of H₀=75 km s⁻¹ Mpc⁻¹.

2 OBSERVATIONS, DATA REDUCTION AND RESULTS

NIR spectra of Mrk 1239 in the intervals 0.8–2.4 μm and 2.0–4.9 μm (hereafter SXD and LXD, respectively) were obtained at the NASA 3 m Infrared Telescope Facility (IRTF) with the SpeX spectrograph (Ravner et al. 2003), atop Mauna Kea, on April 21, 2002 (UT) and October 24, 2003 (UT) for the SXD data and on April 22, 2002 (UT) for the LXD spectrum. The detector consisted of a 1024×1024 ALADDIN 3 InSb array with a spatial scale of 0.15″/pixel. A 0.8″×15″ slit, oriented east-west, was used during the observations. The spectral resolution was 360 km s⁻¹ at both setups. The total on-source exposure times amount to 1900 s and 1200 s for the April 21 and 22, 2002, and 1200 s for the SXD observation of October 24, 2003. The signal within the central 0.8″×1″ (1″=380 pc) was summed up to obtain the nuclear spectrum. The light distribution of the galaxy was found to be cuspy, being dominated by the unresolved emission from the AGN. The data reduction, extraction and calibration procedures were done using the in-house software SpeXtool (Cushing et al. 2004) and Xtelcor (Vacca et al. 2003), provided by the IRTF Observatory. The spectra in the SXD and LXD settings, observed on consecutive nights, were merged to form a single 0.8–4.9 μm spectrum. The agreement in the continuum level in the overlapping region was excellent, with less than 5% of uncertainty. The SXD spectra obtained in October 2003 also agreed, within 10% of uncertainty, with the continuum level measured in the observation taken in 2002.

Figure 1 shows the final NIR spectra of Mrk 1239 in the rest-frame of the object. In the regions where the atmospheric transmission drops to zero, a straight line was interpolated to connect the adjacent bands. It can be seen that the NIR spectrum is dominated by a strong bump of emission, peaking at 22000 Å, also present in the October 24, 2003 observation. Also prominent in the spectra are emission lines of Hγ, He 1 and [S III]. No absorption lines that may indicate the presence of circumnuclear stellar population were detected. Since the main focus of this work is the continuum emission, the analysis of the line spectra is left for a future publication. To our knowledge, the only NIR spectroscopy available in the literature on this source is the J and K spectra of Heisler & De Robertis (1999). Because of the non-photometric conditions in which they were taken, there is a lack of continuity in the continuum level between the bands, preventing us to make any meaningful comparison. However, in Fig. 2g of Heisler & De Robertis (1999), the J continuum rises toward longer wavelengths. In the K-band, it continues rising up to 2.2 μm, where it seems to become flat, in accordance to our observations.

In addition to the NIR data, long-slit optical spectroscopy on Mrk 1239 was obtained on the nights of March 19 and 20, 2002, with the Cassegrain spectrograph attached to the 2.15 m telescope of the CASLEO Observatory, Argentina. The spectra cover the interval 3700–9600 Å and were obtained with a 2″ slit width and a 300 l/mm grating. The extraction and reduction process followed the standard IRAF procedure. As in the NIR region, the light profile distribution of the galaxy is dominated by the unresolved emission of the AGN. The aim of the optical data is to complement the NIR spectrum to map the optical-NIR continuum of this source. No significant variation (less than 5%) in the level of the continuum emission was detected in the overlapping region between the optical and NIR spectra (0.8–0.95 μm).

3 THE INTERNAL EXTINCTION IN MRK 1239 AND THE CONTINUUM EMISSION

In order to properly interpret the strong excess of NIR emission in Mrk 1239, it is first necessary to de-redden its optical-NIR continuum. To this purpose, we used as reference, the spectrum of the NLS1 galaxy Ark 564, whose continuum emission is well known and we assumed as typical of a NLS1 galaxy. Flux-calibrated FOS HST spectra in the optical region and SpeX IRTF spectra (Contini et al. 2003) were employed.

We started by dereddening the Ark 564 data by Galactic (E(B–V)=0.03) and internal extinction (E(B–V)=0.14), as determined by Grenshaw et al. (2002). The reddening law of Cardelli et al. (1989) with Rᵥ=3.1 was used to this purpose. Then, assuming that the form and slope of the extinction-corrected optical continuum in Ark 564 represents the intrinsic continuum of Mrk 1239, we de-reddened the observed spectra of the latter object (already corrected by a Galactic E(B–V) of 0.065) in small steeps.
until the form of its optical continuum matches that of former. An
significant NIR excess of emission in Ark 564. Line) and another that dominates the NIR (dotted line). Note the lack of
continuum emission of the latter object was modeled in terms of a sum of two
dereddened by E(B-V)=0.54, with that of Ark 564. The box in the upper
right corner shows a zoom in the optical region of both galaxies. The con-
derived spectral indices are $\alpha_{\text{opt}} = -1.93$ and $\alpha_{\text{NIR}} = -0.2$ for the
optical and NIR regions, respectively. From Figure 2 we see that this
composite function cannot describe the continuum emission in the $1-4\, \mu m$ region of Mrk 1239. The strong excess of emission that
rises above the level predicted by the optical plus NIR power-laws indicates the necessity of an additional component.

An inspection to the overall shape of the bump suggests that it approaches that of a blackbody distribution. In order to test this hypothesis, we fitted a composite function – two power-laws, plus a Planck curve, to the observed optical-NIR SED. Additional
constraints to the fit was imposed by adding photometric points for
the L ($3.5\, \mu m$) and N ($10.5\, \mu m$) bands, taken from the literature
(Spinoglio et al. 1995; Maiolino et al. 1995). In the fit, the
power-law indices were constrained to the values found for Ark 564 (see above) while the temperature and amplitude of the blackbody function were left as free parameters. The results, displayed in Figure 2 show that a composite function, with a blackbody of temperature $T_{bb}=1210$ K, provides an excellent description to the the excess of emission over the power-laws. It should be noted here that the
use of blackbody instead of a greybody is preferred because of the
smaller number of free parameters that the former function requires. In the absence of observational constraints that justifies the use of a more complex function, they choice is for the one that offers an adequate solution with the minimum number of parameters to fit. See also Sect. 4.

What is the origin of each of the three continuum components, all emitted in the inner 380 pc of the AGN? We associate the
power-law that dominates the optical region to the long-wavelength side of the UV/optical continuum component, often called the
big blue bump (BBB), thought to be emitted from an accretion disk around a supermassive black hole (Malkan 1983; Zheng et al.
1997; Constantin & Shields 2003). The NIR power-law is likely associated to the black-end tail of the much broader infrared ex-
cess that dominates the IR SED of AGN, usually attributed to cold dust ($T \sim 40-80$ K), warmer than dust in normal spiral galaxies
(Edelson & Malkan 1986), with peak emission at 60 $\mu m$, and ob-
served in Mrk 1239 (Heisler & De Robertis 1998).
and higher than the sublimation temperature of silicate grains (T ~1000 K; Granato & Danese 1994). Considering that our spatial resolution is limited to ~380 pc, it is very likely that dust at higher temperatures exists closer to the central source, ruling out the possibility of silicates as the main component of the nuclear dust grains.

Using the temperature of the blackbody as the average temperature of the graphite grains and a K band flux of 5.93 x 10^{-25} erg s^{-1} cm^{-2} Hz^{-1} at 2.2 μm found for the blackbody component after subtracting the underlying composite power-laws, we can roughly estimate the dust mass associated with the bump. Following Barvainis (1987), the infrared spectral luminosity, in ergs s^{-1} Hz^{-1}, of an individual graphite grain is

$$L_{ir,gr} = 4π a^2 σT_{gr}^4$$

where a is the grain radius, $q_a = q_{H} T^7$ is the absorption efficiency of the grains and $B_{ir}(T_{gr})$ is the Planck function for a grain of temperature $T_{gr}$. Adopting, as in Barvainis (1987), a value of $a = 0.05$ μm for graphite grains and $q_a = 0.058$ and setting $T_{gr} = 1220$ K, we find $L_{ir,gr} = 9.29 × 10^{-18}$ ergs s^{-1} Hz^{-1}.

The total number of emitting grains (hot dust) can be approximated as $N_{HIID} \approx L_{IR,IR}/L_{ir,gr}$.

Finally, for graphite grains, with density $ρ_g = 2.26$ g cm^{-3}, $M_{HIID} \approx 4.12 × 10^3 N_{HIID} ρ_g$. Taking Mrk 1239 at a distance of 79.7 Mpc ($z = 0.00199$, H_0 = 75 km s^{-1} Mpc^{-1}), we obtained $N_{HIID} = 5.41 × 10^{46}$ and $M_{HIID} = 2.7 × 10^{-3}$ M⊙.

Table 1 compares the mass of hot dust derived for Mrk 1239 to that found in other AGNs. Our calculations show that Mrk 1239 harbors the second largest mass of hot dust reported to date in the literature for an AGN, only surpassed by NGC 7469. Note, however, that except for Mrk 766, all other previous measurements are based on photometric data, which do not take into account the underlying featureless continuum that we subtracted. Had we used the peak flux of the continuum, we would have obtained a value of 5.3 M⊙, ranking Mrk 1239 as the AGN with the largest content of hot dust found to date. The presence of dust near to sublimation temperature in Mrk 1239 has been largely predicted by dust emission models. In fact, the onset of the broad strong bump of emission at 1 μm, with peak at ~60 μm, is set by the dust sublimation temperature of graphite grains at ~1500 K. Why in Mrk 1239 exists such a large amount of hot dust, to the extent of creating a noticeable shoulder in the much broader IR SED attributed to warm dust, cannot be tell from our data. No doubt that Mrk 1239 is an excellent target to be studied spectroscopically with Spitzer in order to study the broad band IR emission of this object.

Regarding to the location of the hot dust, our aperture size implies that it must reside within the inner 380 pc from the centre. However, the high temperature of the dust imposes a tighter constraint to the location of its emitting region: the inner 100 pc. This value is deduced by inspecting Fig. 3 of Marco & Alloin (1998), where a plot of dust temperature as function of distance from the nucleus was constructed for NGC 7469. Note that we have as-

### Table 1. Masses of hot dust found in AGNs

| Galaxy   | Mass (M⊙) | Reference               |
|----------|-----------|-------------------------|
| Mrk 1239 | $2.7 × 10^{-2}$ | This work               |
| NGC 7469 | $5.2 × 10^{-2}$ | Marco & Alloin 1998    |
| Fairall 9 | $2.0 × 10^{-2}$ | Clavel et al. 1989     |
| NGC 3783 | $2.5 × 10^{-3}$ | Glass 1992              |
| Mrk 766  | $2.1 × 10^{-3}$ | Rodríguez-Ardila et al. 2005 |
| NGC 1566 | $7.0 × 10^{-4}$ | Baribaud et al. 1992   |

### Figure 3.

Intrinsic optical, NIR and MIR SED of Mrk 1239. The full circles are aperture photometry. In the JHK bands, they were taken from 2MASS. For the L and N region, they were taken from the literature (see text). The dotted-dashed and the dotted curves are the optical and NIR power-law functions, respectively, found for Ark 564. The dashed curve is the black-dotted-dashed and the dotted curves are the optical and NIR power-law functions, respectively, found for Ark 564. The dashed curve is the black-dotted-dashed and the dotted curves are the optical and NIR power-law functions, respectively, found for Ark 564. The dashed curve is the black-dotted-dashed and the dotted curves are the optical and NIR power-law functions, respectively, found for Ark 564. The dashed curve is the black-dotted-dashed and the dotted curves are the optical and NIR power-law functions, respectively, found for Ark 564. The dashed curve is the black-dotted-dashed and the dotted curves are the optical and NIR power-law functions, respectively, found for Ark 564.
sumed that the dust in Mrk 1239 has similar properties to that of NGC 7469. Further support to this distance can be obtained following the results for NGC 1068 (Marco & Alloin 2004). These authors concluded that hot dust ($T_{gr}=1500$ K) should be extremely confined and located at a radius less than 4 pc. Although the precise location of the hot dust cannot be distinguished from our data, both scenarios are in accord to the polar scattering model of Smith et al. (2004). Likely, the combined effect of hot dust associated to the outer layers of the torus and the inner hot dust of the polar scattering cone contribute to enhance the bump observed in Mrk 1239. In fact, 10 μm imaging of this object presented by Gorjian et al. (2004) shows clear evidence of bright extended emission in a cone-like structure, with the apex of the cone located at the nucleus. Although evidence of this extended emission is not seen in our data, we espculate that the hottest dust component should indeed contribute to the observed bump. No doubt, our results provides the first direct spectroscopic evidence of hot dust in AGN and show the potential that NIR spectroscopy has at unveiling that component.

If the strong NIR excess observed in Mrk 1239 is indeed thermal emission from very hot dust, one can ask why we only see emission at a single temperature if one would expect a range of temperatures? In that case, the NIR excess should resemble more closely to a sum of blackbody curves of decreasing temperatures. This question can be answered if we remember that the IR emission in Mrk 1239 is largely dominated by a much stronger bump, peaking at 60 μm (see, for example, Figure 7 of Grupe et al. 2004, where the broadband continuum of this source is presented), indicating that a large interval of dust temperatures indeed dominates the bulk of the IR emission over the hot one.

5 FINAL REMARKS

In this letter we have reported the first discovery of an isolated NIR bump of emission in the NLS1 galaxy Mrk 1239. The continuum steeply rises toward longer wavelengths redward of 1 μm, peaking at 2.2 μm, where it starts to fall smoothly with wavelength. This excess of emission dominates the region between 1-5 μm. After comparing the optical continuum with that of Ark 564, we found that the continuum in Mrk 1239 is reddened by E(B-V)=0.54, appreciably larger for a type 1 object. This result agrees with polarimetry data, which points out towards a dusty polar scattering region. In order to adequately reproduce the NIR continuum, a Planck distribution of T≈1200 K is needed to account for the strong excess of emission over a featureless continuum of power-law form. We interpreted this component in terms of very hot dust, near its sublimation temperature, very likely located both in the upper layers of torus and close to the apex of the polar scattering region. If our hypothesis is correct, we have provided additional spectroscopic evidence of the presence of the putative torus of the unified model of AGNs.

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