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Dust in active nuclei

I. Evidence for "anomalous" properties

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Abstract. We present observational evidences that dust in the circumnuclear region of AGNs has different properties than in the Galactic diffuse interstellar medium. By comparing the reddening of optical and infrared broad lines and the X-ray absorbing column density we find that the $E_{B-V}/N_{\rm H}$ ratio is nearly always lower than Galactic by a factor ranging from ∼3 up to ∼100. Other observational results indicate that the $A_V/N_{\rm H}$ ratio is significantly lower than Galactic in various classes of AGNs including intermediate type 1.8–1.9 Seyferts, hard X–ray selected and radio selected quasars, broad absorption line QSOs and grism selected QSOs. The lack of prominent absorption features at 9.7 μm (silicates) and at 2175 Å (carbon dip) in the spectra of Seyfert 2s and of reddened Seyfert 1s, respectively, add further evidence for dust in the circumnuclear region of AGNs being different from Galactic. These observational results indicate that the dust composition in the circumnuclear region of AGNs could be dominated by large grains, which make the extinction curve flatter, featureless and are responsible for the reduction of the $E_{B-V}/N_{\rm H}$ and $A_V/N_{\rm H}$ ratios. Regardless of the physical origin of these phenomena, the reduced dust absorption with respect to what expected from the gaseous column density should warn about a mismatch between the optical and the X-ray classification of the active galactic nuclei in terms of their obscuration.

Key words. galaxies: Seyfert – galaxies: nuclei – galaxies: ISM – dust, extinction

1. Introduction

The properties of the circumnuclear gas are a key issue to understand the physics of Active Galactic Nuclei (AGNs). In particular, gas obscuration has important consequences on the classification of AGNs (Antonucci 1993), on their infrared emission (Granato et al. 1997; Pier & Krolik 1993) and also on the X-ray background (Setti & Woltjer 1989). AGNs are, optically-wise, divided in two main classes: type 1 AGNs, showing broad permitted emission lines, and type 2 AGNs, which only show narrow emission lines. The Unified Model assumes that AGNs of both classes host the same kind of nuclear engine and ascribes their differences solely to orientation effects with respect to an obscuring gaseous medium, possibly arranged in a torus-like geometry. For those lines of sights intercepting the obscuring torus, both the Broad Line Region (BLR, <1 pc in size) and the nuclear engine are obscured and only the much more extended Narrow Line Region (NLR) can be observed. This model has gained success from a large number of observational tests (see Antonucci 1993 for a review). In particular, X-ray observations have supported the unified scenario by discovering large columns of absorbing gas in type 2 AGNs (e.g. Awaki et al. 1991; Turner et al. 1997; Maiolino et al. 1998; Risaliti et al. 1999). Also, spectroscopic observations in the infrared, where dust absorption is greatly reduced, detected broad permitted lines in several AGNs which are classified as type 2 in the optical.

However, the properties of the absorbing medium result to be more complex with a more quantitative analysis. Maccacaro et al. (1982) first noted, in a few AGNs, that the dust reddening affecting the BLR is significantly lower than expected from the $N_{\rm H}$ measured in the X-rays, assuming a Galactic standard extinction curve and dust-to-gas ratio. An analogous result was obtained by Reichert et al. (1985). Indications for a low value of $A_V/N_{\rm H}$ in the obscuring torus were also found by Granato et al. (1997) by modelling the IR emission of AGNs; they ascribed the

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low $A_V/N_{\rm H}$ ratio to the sublimation of dust at the inner face of the torus.

The goal of this paper is to observationally verify the low $E_{B-V}/N_{\rm H}$ and low $A_V/N_{\rm H}$ phenomena with a higher confidence (Sects. 2 and 3). We also investigate dust spectral signatures which directly probe the properties of dust grains in the circumnuclear region of AGNs. Most of the interpretation of these observational effects is addressed in a companion paper (Maiolino et al. 2001, Paper II). Finally, note that in this paper we will often distinguish the $E_{B-V}/N_{\rm H}$ and the $A_V/N_{\rm H}$ ratios since, as discussed in Paper II, in the circumnuclear region of AGNs dust reddening and obscuration are not necessary tied by the Galactic standard relation ($A_V/E_{B-V} = 3.1$).

Throughout this paper we will assume a cosmology with $H_0 = 65$ and $q_0 = 0.5$.

2. Evidence for a low $E_{B-V}/N_{\rm H}$

2.1. Sample selection and reddening determination

We have defined a sample of AGNs whose X-ray spectrum shows evidence for cold absorption (hence a measure of the gaseous column density $N_{\rm H}$ along the line of sight) and whose optical and/or IR spectrum show at least two *broad* lines that are not completely absorbed by the dust associated to the X-ray absorber. This sample includes intermediate type (1.8–1.9) Seyferts, type 2 Seyferts with broad lines in the near-IR, and a few type 1–1.5 Sy characterized by cold absorption in the X-rays. We do not consider AGNs whose X-ray spectrum shows evidence for a warm absorber, since very likely the latter is not associated to the obscuring torus (Netzer 2000) and also because the gaseous column inferred for a warm absorber is strongly model-dependent (this is discussed further in Sect. 5). We do not consider cold absorbers with partial covering, since also in this case the absorber is not associated to the obscuring torus, but to matter very close to the X-ray source, possibly the BLR clouds (Maiolino 2000). In the cases of dual absorbers we assume the $N_{\rm H}$ of the lower column density absorber, both to be conservative and because the higher density absorber has generally a low partial covering (Maiolino 2000). Table 1 lists the sources in our sample.

The gaseous $N_{\rm H}$ along the line of sight is derived directly by the photoelectric cutoff in the X-ray spectrum, provided that the signal-to-noise is high enough. Table 1 lists the $N_{\rm H}$ derived for the sources in our sample along with the *intrinsic* 2–10 keV luminosity (i.e. absorption corrected). As mentioned above we excluded objects whose X-ray spectrum shows evidence for warm absorption as based on the presence of the absorption edges of OVII and OVIII at 0.74 and 0.87 keV respectively. For most of the objects in Table 1 the X-ray absorption is "cold", in the sense that the chi-squared of the spectral fit is significantly better with the latter model than with a warm absorption model (this is discussed in some of the references reported in Table 1). For some objects the signal-to-noise of the X-ray spectrum is not high enough to discard warm absorption; this is certainly the case for SAX0045-25, SAX1218+29, SAX1519+65, AXJ0341-44, and Mkn231. Yet, the spectral shape in most of the latter cases is such that a fit with a warm absorber would require an unrealistically high column of warm gas ($\sim 10^{24}$ cm^{-2}, possibly with the exception of Mkn231) thus favoring the cold absorption model. Finally, even in those cases for which cold absorption provides a better fit with respect to a warm absorber this generally does not exclude that both components are present. Also, ionized gas along the line of sight might not be sampled by the OVII and OVIII absorption edges if the ionization stage is too low or too high (Kraemer et al. 1999, 2000; Brandt et al. 1996; Reynolds & Fabian 1995). However, the presence of ionized gas along the line of sight which is not detected in the X-ray spectra would make the total column of gas (neutral+ionized) higher than inferred assuming a single cold, component and, as we shall see, the problem of the reduced $E_{B-V}/N_{\rm H}$ would be even worse.

Ratios between broad components of the hydrogen lines compared to the intrinsic values give the amount of dust reddening affecting the BLR. However, radiative transport and collisional excitation effects in the extreme conditions of the BLR clouds ($n \sim 10^9$ cm^{-3}) can affect the standard hydrogen line ratios expected in the case B recombination. For instance, BLR models expect the Hα/Hβ Balmer decrement to range from the "standard" ratio of 3.1 up to a factor of 3 higher (Rees et al. 1989; Netzer et al. 1985; Mushotzky & Ferland 1984), this is mostly due to the large optical thickness of Hβ whose deexcitation transition has a high probability of being split into Paα and Hα. Nonetheless, the Hα/Hβ ratio observed in Sy1s and QSOs is often consistent with the standard case B value. Should the intrinsic ratio be higher, the observed Hα/Hβ compared to the case B value provides at least an upper limit to the reddening. Ratios between infrared broad hydrogen lines (Paβ, Paα and Brγ) provide a more reliable measure of the reddening, since they are much less affected by the radiative transport effects discussed above. In some cases the broad lines were not measured simultaneously and therefore variability might have affected the real ratios.

As a consequence of what is discussed above we adopted the following criteria to select the broad line pairs to be used for the reddening determination. When more than two broad lines were available, to avoid problems related to the variability we chose those lines which were observed (nearly) simultaneously. The cases for which the broad lines were measured simultaneously are marked with a "*" in Col. 6 of Table 1 (these cases are the majority). When more than two simultaneous broad lines were available we used the ratios involving only near-IR lines rather than Hα/Hβ. Finally, Paβ/Hα, Paα/Hα and (in one case) Hβ/Hδ were used only in a few cases. The line ratio adopted to estimate the reddening for each object is given in Col. 6 of Table 1.

To determine the reddening E_{B-V} from the broad line ratios an extinction curve must be assumed. We have

Table 1. Sample of AGNs whose X-ray spectrum shows evidence for cold absorption and whose optical and/or IR spectrum shows at least two broad lines. Objects are sorted by increasing X-ray luminosity. Notes: [a] reddening estimated assuming a standard Galactic extinction curve; [b] gaseous column density inferred from the hard X-rays in units of 10^{20} cm^{-2}; [c] $E_{B-V}/N_{\rm H}$ ratio relative to the standard Galactic value of 1.7 10^{-22} cm^{-2}; [d] lines ratio used to estimate the reddening ("cont." indicates objects for which the reddening was estimated by fitting also the continuum), stars mark line pairs which were observed (nearly) simultaneously; [e] 2–10 keV *intrinsic* luminosity (i.e. corrected for gaseous absorption); [f] references for the optical, infrared and X-ray data: 1) Ho et al. (1999), 2) Koratkar et al. (1995), 3) Bassani et al. (1999), 4) Filippenko & Sargent (1988), 5) Maiolino et al. (2000), 6) Veilleux et al. (1997), 7) Marconi et al. (in prep.), 8) Rix et al. (1990), 9) Maiolino et al. (1996), 10) Vignali et al. (2000), 11) Gilli et al. (2000), 12) Halpern et al. (1999), 13) Boyle et al. (1998), 14) Feldmeier et al. (1999), 15) Crenshaw et al. (1988), 16) Sambruna et al. (1999), 17) Stirpe et al. (1990), 18) Aguero et al. (1994), 19) Severgnini et al. (in prep.), 20) Turner et al. (1999), 21) Lacy et al. (1982), 22) Winkler et al. (1992), 23) Fiore et al. (1999)

Name	E^a_{B-V}	$N^b_{\rm H}$ (10^{20} cm^{-2})	$E_{B-V}/N^c_{\rm H}$ (rel. Gal.)	z	Redd. est.[d]	Log $L^e_{\rm X}$ (erg s^{-1})	Refs.[f] opt/IR	X
M 81	0.66 ± 0.25	$9.4^{+0.7}_{-0.6}$	$4.11^{+1.57}_{-1.52}$	0.00037	Hα/Hβ^*	40.52	4	3
NGC 4639	0.38 ± 0.25	$7.3^{+5.6}_{-5.1}$	$3.04^{+2.98}_{-3.02}$	0.00544	Hα/Hβ^*	40.92	1	1
NGC 5033	0.72 ± 0.24	$8.7^{+1.7}_{-1.7}$	$4.84^{+1.92}_{-1.87}$	0.00292	Hα/Hβ^*	41.10	2	3
NGC 1365	1.5 ± 0.3	2000^{+400}_{-500}	$0.022^{+0.005}_{-0.005}$	0.005	Brγ/Paβ^*	42.42	7	3
Mk 231	0.34 ± 0.10	370^{+260}_{-150}	$0.054^{+0.027}_{-0.041}$	0.042	Paα/Hα^*	42.66	21	20
IRAS 13197-1627	0.47 ± 0.15	3000^{+1100}_{-1000}	$0.0092^{+0.0042}_{-0.0044}$	0.01654	Hα/Hβ^*	42.66	18	19
SAX J1519+65	0.55 ± 0.2	1580^{+410}_{-320}	$0.020^{+0.007}_{-0.012}$	0.044	cont.	42.74	5	5
N5506	1.59 ± 0.59	340^{+26}_{-12}	$0.27^{+0.10}_{-0.10}$	0.00618	Brγ/Paβ	42.96	8,9	3
N2992	0.58 ± 0.41	90^{+3}_{-3}	$0.38^{+0.26}_{-0.27}$	0.0077	Brγ/Paβ^*	43.05	11	11
SAX J0045-25	0.5 ± 0.3	390^{+870}_{-260}	$0.075^{+0.067}_{-0.173}$	0.111	cont.	43.06	5	5
Mkn6	0.72 ± 0.13	333^{+29}_{-16}	$0.13^{+0.02}_{0.02}$	0.01847	Hα/Hβ^*	43.17	14	14
MCG-5-23-16	0.61 ± 0.59	162^{+23}_{-21}	$0.220^{+0.214}_{-0.215}$	0.00827	Brγ/Paβ	43.22	6	3
SAX J1218+29	0.65 ± 0.2	1250^{+1900}_{-750}	$0.030^{+0.019}_{-0.047}$	0.176	cont.	43.29	5	5
IRAS 05189-2524	0.71 ± 0.35	840^{+80}_{-65}	$0.049^{+0.025}_{-0.025}$	0.042	Paα/Paβ^*	43.44	19	19
NGC 526a	1.0 ± 0.25	150^{+14}_{-14}	$0.39^{+0.10}_{-0.10}$	0.01922	Paβ/Hα	43.55	7,22	3
3C 445	0.88 ± 0.21	580^{+320}_{-180}	$0.088^{+0.034}_{-0.053}$	0.057	Hα/Hβ^*	43.79	15	16
SAX J1353+18	0.86 ± 0.15	154^{+37}_{-32}	$0.33^{+0.09}_{-0.10}$	0.2166	Paα/Hα	43.91	7,23	10
AX J0341-44	<1.59	1000^{+400}_{-400}	<0.09	0.672	Hβ/Hγ^*	44.21	12	13
PG 2251+11	0.34 ± 0.13	60^{+30}_{-22}	$0.33^{+0.17}_{-0.21}$	0.3255	Hα/Hβ^*	44.67	17	16

assumed the "standard" Galactic extinction curve (Savage & Mathis 1979). To derive the extinction we also assumed a foreground screen, which is a reasonable assumption given that the BLR is within the sublimation radius (and therefore mostly dust-free) and that the torus is probably more extended than the BLR (Paper II). Column 2 of Table 1 lists the dust reddening toward the BLR derived for each object.

We also include in our study three AGNs (namely SAX J0045-25, SAX J1218+29, SAX J1519+65) whose reddening was not inferred from the ratios of broad hydrogen lines but by a detailed fit to the continuum and of the *EW* of the H lines. More specifically, the optical spectrum (including shape, stellar features and broad H lines), along with near-IR to U-band spectroscopic measurements, were fitted with stellar population synthesis templates of various ages combined with an AGN template reddened by various degrees of extinction. The three free parameters required to fit the data were the relative contribution of the stellar and of the AGN component, the age of the stellar population and the reddening of the AGNs. For a more detailed description of the method see Maiolino et al. (2000) and Vignali et al. (2000). Although the large number of observational constraints allow a relatively good determination of the three free parameters, the determination of the reddening is not as accurate as for the broad lines ratio method. However, for one object (SAX J1353+18) both methods could be used and gave consistent results (Maiolino et al. 2000; Vignali et al. 2000). The interesting property of these objects is that they were selected (and actually discovered) in the hard X-rays (Fiore et al. 1999) and, therefore, are not affected by some of the biases that might affect the other objects and which will be discussed later.

2.2. Evidence for a low $E_{B-V}/N_{\rm H}$

In Col. 4 of Table 1 we report the $E_{B-V}/N_{\rm H}$ ratio relative to the Galactic standard value of 1.7 10^{-22} mag cm^2 (Bohlin et al. 1978). Except for a few cases, $E_{B-V}/N_{\rm H}$ is significantly lower than the Galactic standard value, by a factor ranging from a few to ~100. This is

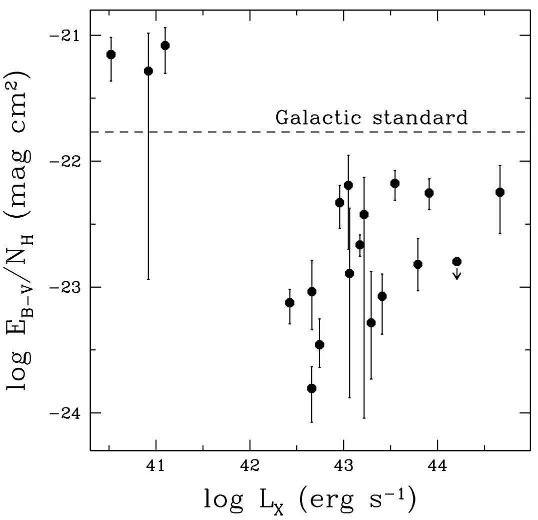

Fig. 1. $E_{B-V}/N_{\rm H}$ ratio as a function of the intrinsic 2–10 keV luminosity for the objects in our sample. The dust reddening E_{B-V} is estimated assuming a Galactic standard extinction curve as discussed in the text. The gaseous column density $N_{\rm H}$ is derived from the photoelectric cutoff in the hard X-rays

graphically shown in Fig. 1 where the $E_{B-V}/N_{\rm H}$ ratio relative to Galactic is plotted as a function of the intrinsic X-ray luminosity. Figure 1 does not really show a correlation between the two quantities, but rather a bimodal behavior: AGNs with luminosities higher than 10^{42} erg s^{-1} are systematically characterized by $E_{B-V}/N_{\rm H}$ lower than Galactic, though they show a large spread, while those few Low Luminosity AGNs (LLAGNs) in our sample, with $L_{\rm X} < 10^{42}$ erg s^{-1}, are characterized by $E_{B-V}/N_{\rm H}$ consistent with, or even higher, than Galactic. The markedly different behavior of LLAGNs with respect to the other AGNs in the sample, might reflect the fact that the physics of these objects is intrinsically different from the "classical" AGNs, as suggested by various authors (e.g. Ho 1999). In the following we will focus on the other AGNs in our sample, which have luminosities more typical of classical Seyfert galaxies or of QSOs.

Admittedly, our sample is not very large and is not representative of the population of obscured AGNs, given that we had to select our objects in a relatively narrow range of absorptions. In particular, the absorption must be low enough to enable us to detect the broad lines. We cannot exclude the existence of AGNs (in the normal-high luminosity range $> 10^{42}$ erg s^{-1}) with an $E_{B-V}/N_{\rm H}$ consistent with Galactic. For instance, objects with $N_{\rm H}$ higher than a few times 10^{22} cm^{-2} and *Galactic* $E_{B-V}/N_{\rm H}$ would be characterized by an extinction A_V so high to make broad lines undetectable, possibly even in the IR, and therefore would be excluded from our sample. Nonetheless, we would like to stress the following results: 1) the existence of a population of AGNs characterized by a value of $E_{B-V}/N_{\rm H}$ significantly lower than Galactic is proven beyond any doubt; 2) with the exception of the three LLAGNs discussed above, we could not find AGNs whose $E_{B-V}/N_{\rm H}$ is consistent with the Galactic standard value[1]. Determining if this is a property common to all AGNs or determining what fraction of them is characterized by this feature cannot be done with the current sample alone.

3. Evidences for a low A_V/N_H

The evidence for a low $E_{B-V}/N_{\rm H}$ discussed above might be translated into evidence for a low $A_V/N_{\rm H}$ if a standard conversion factor $A_V/E_{B-V} = 3.1$ applies to these objects. Indeed, such a conversion factor might not apply and, therefore, a reduced reddening does not necessary imply a reduced absorption. However, there are other observational evidences supporting the idea that also the $A_V/N_{\rm H}$ ratio AGNs is generally significantly lower than the Galactic standard value.

3.1. The intermediate 1.8–1.9 type Seyferts

The intermediate type Seyferts discussed in the former section are only a small fraction of those available in various Seyfert samples; in particular the discussion in Sect. 2 is limited to the sources for which enough information is available to derive both reddening and gaseous column density. In some of these objects the weakness of the broad Hβ or Hα lines is due to intrinsic properties of the BLR (Goodrich 1995), but more often the weakness of the broad lines lines is ascribed to dust absorption (Maiolino & Rieke 1995). In the latter case the extinction must be about $A_V \approx 3$, given that usually in these objects the faint broad lines have a flux similar to the narrow components, while in type 1 objects broad lines are about 10 times stronger than the narrow lines. On the other hand, most of the intermediate type Seyferts are characterized by an absorbing column density between 10^{22} cm^{-2} and 10^{23} cm^{-2} and, in some cases, even higher than 10^{23} cm^{-2} (Risaliti et al. 1999). With a Galactic conversion factor such column densities would imply an extinction of $A_V \approx 30$, which would obviously make any broad line undetectable (unless reflected, Paper II). This suggests that, at least in this class of objects, the $A_V/N_{\rm H}$ ratio must be about a factor of 10 lower than Galactic.

3.2. QSOs with hard X-ray absorption

Local Seyfert 1 galaxies are generally characterized by an X-ray spectrum with low or no cold absorption, in agreement with the extinction inferred by their optical spectra. However, at higher luminosities, there is evidence for a population of QSOs whose hard X-ray spectrum is characterized by significant cold absorption along the line of sight although their optical spectrum has prominent broad

[1] Note that even with the bias discussed above we would have expected to find some object with Galactic $E_{B-V}/N_{\rm H}$, at least in those cases with $N_{\rm H} \geq 10^{22}$ cm^{-2} and observed in the near-IR.

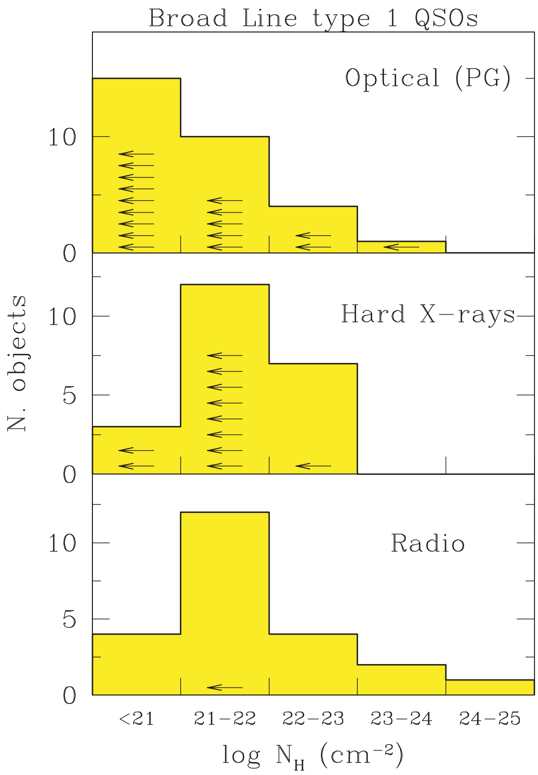

Fig. 2. Distribution of gaseous absorbing column density, as inferred from hard X-ray observations, for various samples of type 1, broad line AGNs, more specifically: a subsample of the PG QSOs (top), a sample of hard X-ray selected QSO (middle) and a sample of radio selected AGNs (bottom)

lines and, usually, also a blue continuum typical of unabsorbed AGNs.

In particular, although most of the optically selected PG QSOs do not show evidence for X-ray gaseous absorption in excess of the Galactic value, a few of them are affected by an excess absorption with $N_{\rm H} > 10^{21}$ cm^{-2}. This is shown in the top panel of Fig. 2, where the distribution of cold absorbing columns, as inferred from the hard X-rays, is reported for the PG QSOs.

Obviously, even a small amount of dust associated with the gaseous column along the line of sight can redden the QSO continuum enough to be missed by $U-B$ color selection criterion of the PG survey. Indeed, surveys of type 1 QSOs selected at wavelength less sensitive to dust obscuration and reddening have found a larger fraction of objects which show evidence for significant gaseous absorption. In particular, the lower two panels of Fig. 2 show the distribution of $N_{\rm H}$ for the type 1 QSOs in the ASCA survey presented by Akiyama et al. (2000) and in the radio-selected type 1 AGNs presented by Sambruna et al. (1999). These distributions clearly show a larger fraction of type 1 AGNs with $N_{\rm H}$ even in excess of 10^{22} cm^{-2}. On the other hand, the prominent broad lines and, often, the blue continuum (although not as "blue" as for the PG QSOs) suggest that the optical absorption and reddening cannot be large. In particular, Akiyama et al. (2000) show that, although significant X-ray absorption is observed in their ASCA selected objects, the ratio between optical and hard X-ray emission[2] is not different from soft X-ray selected QSOs (i.e. not affected by significant absorption). This indicates that optical absorption must be lower than about 1 mag and, together with the $N_{\rm H}$ inferred from the X-rays, indicates an $A_V/N_{\rm H}$ about a factor of ten lower than Galactic.

The HELLAS BeppoSAX survey (Fiore et al. 1999; La Franca et al. in prep) has also found some type 1 blue QSOs with flat X-ray spectra suggesting large columns of gas along our line of sight. Although statistically less relevant than the surveys mentioned above, we could study some of these blue X-ray–absorbed QSO more in detail (e.g. Maiolino et al. 2000): we found an E_{B-V} which is a factor of ∼30 lower than expected from the X-ray absorbing $N_{\rm H}$ and a Galactic $E_{B-V}/N_{\rm H}$.

Within this context it is puzzling that, at variance with the ASCA and BeppoSAX results, Chandra has not found a large number of objects of this class so far (Fiore et al. 2000; Brandt et al. 2000b; Mushotzky et al. 2000): only a few blue type 1 QSOs with significant $N_{\rm H}$ were discovered by Chandra's surveys. Possibly this is due to the sensitivity of Chandra which peaks below 2 keV and, therefore, probably biases the results in favor of soft, little absorbed X-ray sources. XMM, whose sensitivity is much more uniform up to ∼7 keV, should tackle this issue.

3.3. Broad Absorption Line QSOs

Probably the most extreme case of type 1 AGNs with low $A_V/N_{\rm H}$ are the Broad Absorption Line (BAL) QSOs. Brandt et al. (2000a) and Gallagher et al. (1999) found that these objects are extremely weak both in soft X-rays and hard X-rays with respect to the optical. They suggest that this property is not due their intrinsic SED, but to a large column of absorbing gas along the line of sight, probably related to the same medium seen in UV resonant absorption lines. The X-ray emission, heavily suppressed even in the 2–10 keV band, suggests that the gaseous absorbing column must be relatively high: $\sim 10^{23}$ cm^{-2} or higher. Yet, the optical to UV spectrum is rather typical of normal, unabsorbed QSOs (except for the presence of the broad resonant absorption lines), implying little or no dust absorption. Combined with the large absorbing column inferred from the X-rays, this implies that these objects are characterized by an $A_V/N_{\rm H}$ ratio which is nearly two orders of magnitude lower than Galactic.

3.4. Grism selected QSOs

As mentioned above, even a small amount of dust might redden the QSO spectra enough to exclude them from surveys based on color selection criteria such as the Palomar Green survey. On the other hand, grism QSO surveys are

[2] The hard X-ray flux is not significantly affected by absorption for $N_{\rm H}$ values which are typical of these objects ($N_{\rm H} < 10^{23}$ cm^{-2}, Fig. 2).

mostly based on the detection of broad lines whose flux might be little affected by extinction in the case of a low $A_V/N_{\rm H}$, even if a substantial amount of gas were present along the line of sight. Therefore, grism-selected QSOs are among the best suited objects to search for effects of a low $A_V/N_{\rm H}$ ratio. Indeed, by comparing the optical and X-ray emission of grism selected QSOs, Risaliti et al. (2000) find evidence for a significant population of QSO characterized by a low $A_V/N_{\rm H}$ ratio. The reader is addressed to that paper for an exhaustive discussion.

4. Evidences for peculiar properties of dust grains

In the former two sections we have discussed observational evidences on a reduced dust reddening and absorption towards active nuclei with respect to what would be expected from the gaseous $N_{\rm H}$, assuming a Galactic gas–to–dust ratio and extinction curve. This discrepancy can be ascribed to various effects, as discussed in detail in Paper II. One possibility is that the properties of dust grains in the circumnuclear region of AGNs are different from the diffuse ISM of our Galaxy. In the following we present two observational evidences supporting this scenario.

4.1. The 9.7 μm silicate feature

The silicate feature at 9.7 μm observed in the mid-IR spectra of many Galactic sources is commonly ascribed to silicate grains with sizes smaller than $\sim$3 μm. Ground-based mid-IR studies of type 2 Seyferts claimed the detection of a deep silicate absorption feature in the spectra of many Sy2s, which was regarded as an evidence supporting the unified model. However, recent ISO spectra have shown that many of such detections were probably spoilt by the narrow bandwidth of the data, limited by the atmospheric transmission. Indeed, the presence of strong PAH features on both sides of the silicate dip prevented a reliable determination of the continuum in ground-based observations. The average ISO spectrum of a sample of Sy2s obtained by Clavel et al. (2000) does not show evidence for any silicate dip, thus questioning the case for a significant absorption feature claimed in former studies. In particular the very conservative upper limits on the EW of the silicate feature given by Clavel and collaborators for the average spectrum of Sy2s ($EW < 0.32$ μm) implies $\tau_{9.7} < 0.6$.

On the other hand the mid-IR continuum produced by the active nucleus is certainly suppressed in Sy2s with respect to Sy1s. This is apparent, as discussed by Clavel et al. (2000), in the much larger equivalent width of the PAH features of Sy2s with respect to Sy1s. In particular, Clavel et al. estimate an average dust extinction in the mid-IR band and, more specifically, at 7.7 μm of about 1.83 mag with a dispersion of $\pm$0.74 mag. For a Galactic dust composition this would give $\tau_{9.7} = 6.2 \pm 2.5$, i.e. one order of magnitude higher than the upper limit of 0.6 derived from the constraints on the silicate absorption feature, as discussed above.

Note that the absorptions derived above assume a uniform foreground screen model. In the reality the emitting region is extended ($\sim$10 pc) and mixed with the absorber, though most of the emission comes from the hot, inner region. As a consequence, the optical depths derived above actually gives an "equivalent" optical depth for screen absorption. Nonetheless, the relation between $\tau_{9.7}$ and $\tau_{7.7}$ does not change much with the geometry of the absorber, since we are comparing two different forms of absorption of the same continuum at nearly the same wavelength. In particular, the relation remains unchanged in the case of partial covering of the absorber (eg. patchy extinction) since the optical depth at 7.7 μm and at 9.7 μm are measured by means of the equivalent width of two features at nearly the same wavelength. In the case that the emitting region is mixed with the absorber the expected depth of the silicate feature is lower. If the emitting region is completely mixed with the absorber (which is an extreme case since the colder absorbing gas must be located in the outer parts with respect to the mid-IR nuclear emitting region) the "equivalent" optical depth in the silicate feature inferred from the (equivalent) $\tau_{7.7}$ should be $\tau_{9.7} = 3.1 \pm 0.68$ which is still much higher than the upper limit given by the non-detection of the silicate feature in absorption. Therefore, although the meaning of the optical depth derived at 7.7 μm and at 9.7 μm depends on the geometry of the circumnuclear emitting/absorbing matter, the discrepancy between these two quantities remains significant and is not to be ascribed to geometrical effects. The only concern to this regard, is that the inner hot region, which is absorbed along our line of sight by the outer colder regions, might be characterized by the silicate feature in emission, as it is observed in Sy1s (Clavel et al. 2000). Since the upper limit on $\tau_{9.7}$ was based on the upper limit on the equivalent width of the 9.7 μm absorption feature assuming an intrinsic featureless continuum, the possible presence of the emission feature implies a higher upper limit on $\tau_{9.7}$. However, even in Sy1s the 9.7 μm silicate emission is relatively faint ($EW \approx 0.25$ μm) and, in the worst case, accounting for this emission feature would only increase the upper limit on $\tau_{9.7}$ by 0.35, i.e. $\tau_{9.7} < 0.95$, which is still much lower than what was derived from the featureless absorption at 7.7 μm ($\tau_{9.7} = 4.8$).

This result is a very convincing indication that although dust must be absorbing the mid-IR nuclear radiation, such dust must have properties different from the Galactic diffuse interstellar medium. As discussed in Paper II the most likely explanation is that dust in the circumnuclear region is predominantly composed of grains with size larger than 3 μm, which do not contribute to the feature at 9.7 μm.

4.2. The 2175 Å carbon dip

The absorption feature at 2175 Å observed in the diffuse interstellar medium was commonly ascribed to small graphite grains with radii $\approx$100–200 Å. More recent

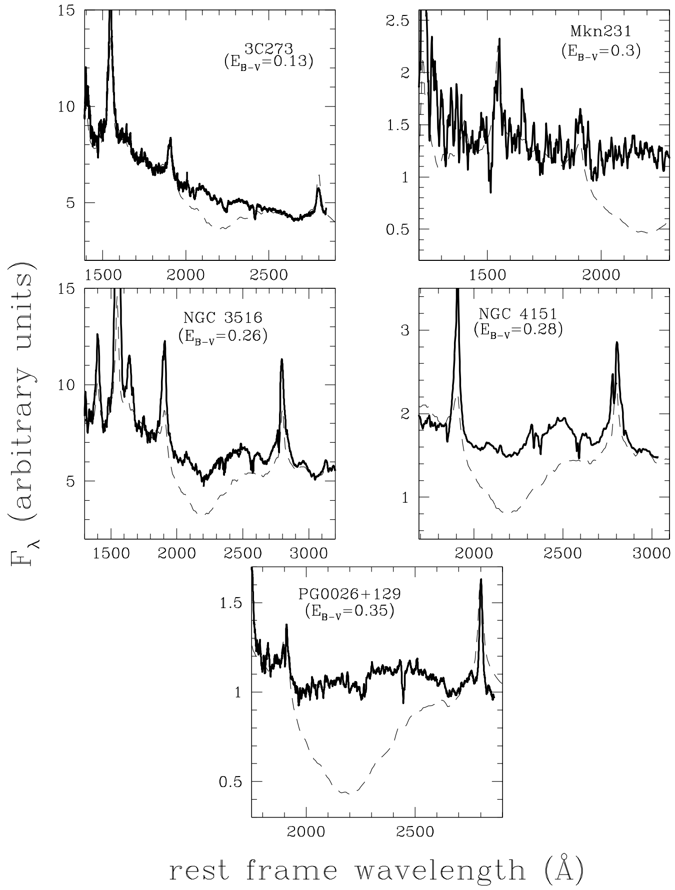

Fig. 3. UV spectra of four type 1 AGN whose broad lines ratios and continuum suggest dust absorption along the line of sight. The thin dashed line is the average spectrum of type 1 AGNs (mostly QSOs) reddened with a standard Galactic extinction curve with an E_{B-V} consistent with that inferred from the broad lines ratio and adapted (within the uncertainties of the E_{B-V} measured with the broad lines) to match the shape of the continuum in those regions not affected by the carbon dip around 2175 Å. Note that the Galactic extinction curve always predicts a significant absorption by this feature which is not observed

studies ascribe most of the profile of this absorption feature to even smaller dust particles (PAHs, Weingartner & Draine 2000). Observing this feature in absorbed AGNs is really difficult since even a small amount of dust generally suppresses nearly completely the UV emission. On the other hand unabsorbed AGNs are generally free of any dust absorption. Yet there are a few type 1 Seyferts and QSOs whose optical and near-IR broad line ratios suggest the presence of some dust reddening along the line of sight (Lacy et al. 1982; McAlary et al. 1986; Puetter et al. 1981). Some of these objects are still relatively bright in the UV and have been observed with the HST spectrometers (FOS and STIS); these are therefore among the best suited objects to look for the carbon dip feature at 2175 Å. In Fig. 3 we show the UV spectra of five of these slightly reddened type 1 AGNs for which we could retrive HST archival spectra. Since we are mostly interested in the continuum shape and in the broad carbon absorption feature the spectra were smoothed to a resolution of about 1000 km s^{-1}. The thin dashed line shows the template of type 1 AGNs obtained by Francis et al. (1991) reddened with the standard Galactic extinction curve by E_{B-V} consistent both with the reddening of the broad lines and with the shape of the UV continuum outside the carbon dip. The most important result is that the Galactic extinction curve systematically predicts a deep feature around 2175 Å which is undetected or much weaker in the observed spectra[3].

As discussed in Paper II, this observational evidence supports the idea that small grains are depleted in the dusty medium responsible for the reddening.

5. Evidences for E_{B-V}/N_H higher than Galactic?

Finally, we shall discuss whether there is any evidence in other previous studies for an $E_{B-V}/N_{\rm H}$ higher than Galactic in any AGNs, besides the three LLAGNs discussed in Sect. 2.

Veilleux et al. (1997) found a few AGNs whose $A_V/N_{\rm H}$ is higher than Galactic (some of which are also included in our sample). For most of these objects a high lower limit to A_V was obtained by comparing a broad Paβ with an upper limit on the broad component of Hα. Paradoxically, as acknowledged by the same authors, for the same objects the comparison between broad Paβ and broad Brγ gives little or no reddening. We believe that this result reflects problems with estimating the upper limits for the broad component of Hα which, most probably, was underestimated. The only object in their paper for which $A_V/N_{\rm H}$ seems larger than Galactic and for which they do not use upper limits on the broad line components is NGC 2992. However, the much higher quality optical and near-IR (simultaneous) spectra obtained by Gilli et al. (2000) clearly indicate an absorption significantly lower than inferred by Veilleux et al. (1997).

A significant fraction of Sy1s shows evidence for highly ionized gas along our line of sight, identified through the presence of absorption edges of OVII and OVIII in the soft X-rays, referred to as "warm absorber" (Reynolds 1997; George et al. 1998). In some cases the X-ray spectra also show evidence for neutral gas in addition to the highly ionized gas. For some of these Sy1s with warm absorbers there is also evidence for dust reddening (Komossa & Fink 1997a, 1997b; Leighly et al. 1997; Komossa & Bade 1998; Reynolds & Fabian 1995). The comparison between the E_{B-V} and the column of neutral gas suggesting an $E_{B-V}/N_{\rm H}$ higher than Galactic. However, we note that there is no reason for the highly ionized gas to be dust-free if it is located at a distance larger than the sublimation radius. Indeed, the columns inferred for the highly ionized component are in agreement (or higher) with the

[3] Note that some of the objects show a small FeII bump at 2500 Å which is stronger than in the template; however, such an emission feature cannot account for the missing dip expected at 2175 Å.

dust reddening for a Galactic dust–to–gas ratio. Secondly, as pointed out by various authors, the ionized gas probably has multiple components at different ionization stages, which are not sampled by the OVII and OVIII edges, but which are characterized by columns high enough to account for the observed reddening (Kraemer et al. 1999, 2000; Brandt et al. 1996; Reynolds & Fabian 1995).

6. Conclusions

We have reported various observational evidences indicating that the dust reddening and absorption of the nuclear region of AGNs is generally much lower than the values expected from the gaseous column density measured in the X-rays, if a standard Galactic dust–to–gas ratio and extinction curve are assumed.

Quantitatively, the most convincing argument supporting a low $E_{B-V}/N_{\rm H}$ ratio is the comparison between the reddening inferred from the optical and infrared broad line ratios and the $N_{\rm H}$ derived from the hard X-rays for a sample of 19 objects. With the exception of three low luminosity AGNs ($L_{\rm X} < 10^{42}$ erg s^{-1}), whose physics might differ from Seyfert– and QSO–like luminosity systems, all the objects appear characterized by an $E_{B-V}/N_{\rm H}$ ratio sistematically lower than the Galactic standard value by a factor ranging from ∼3 up to ∼100.

Also, we have presented additional evidences suggesting a reduced $A_V/N_{\rm H}$ ratio in AGNs. The presence of substantial gaseous absorbing columns ($N_{\rm H} \sim$ a few times 10^{22}) in intermediate type 1.8–1.9 Seyferts contrasts with their optical appearance, but can be reconciled by a low $A_V/N_{\rm H}$ ratio. A more extreme case of this effect is observed in a number of type 1 AGNs (mostly QSOs) whose X-ray spectrum shows evidence for substantial gaseous absorption despite their optical unabsorbed appearance. Two classes of type 1 AGNs which seems to be nearly systematically affected by this phenomenon (i.e. significant X-ray absorption but little, or no, optical absorption) are the Broad Absorption Line QSOs and the grism selected QSOs.

The samples used are probably affected by selection effects, which are discussed in the body of the paper, and therefore cannot be considered as representative of the whole population of AGNs. However, we can certainly state that at least a sub-population of the AGNs is characterized by a low $E_{B-V}/N_{\rm H}$ or $A_V/N_{\rm H}$ with respect to the Galactic value. Also, we could *not* find evidence for a Galactic standard $E_{B-V}/N_{\rm H}$ or $A_V/N_{\rm H}$ ratio in nearly any object.

We presented additional evidences indicating that the properties of dust grains in the circumnuclear region of AGNs are different with respect to the Galactic diffuse interstellar medium:
– although type 2 Seyfert nuclei appear significantly absorbed by dust in the mid–IR, their average ISO spectrum does not show evidence for the silicate absorption feature at 9.7 μm which, instead, is expected to be very deep in case of heavy absorption;
– some type 1 Seyferts which appear affected by some reddening do not show evidence for the carbon dip at 2175 Å, while according to the Galactic standard extinction curve this absorption feature should be prominent in their UV spectra.
Both these observational evidences suggest that dust in the circumnuclear region of AGNs is depleted of the small grains (< 3 μm and 100–200 Å respectively) which are responsible for these absorption features. A dust grain distribution biased in favor of large grains would also make the extinction curve flatter (Laor & Draine 1993). If the bias for large grains is due to coagulation this would also explain the reduced $E_{B-V}/N_{\rm H}$ and $A_V/N_{\rm H}$ (Kim & Martin 1996). A more detailed discussion on the interpretation of these results is given in a companion paper (Maiolino et al. 2001, Paper II).

Regardless of the intepretation of these observational phenomena, these results have important consequences on the unified theories of AGNs. The finding that the dust absorption in generally significanlty lower with respect to what expected from the gaseous column density implies that for several AGNs the optical classification might be de-coupled from the X-ray classification. In particular, AGNs which appear obscured (type 2) in the X-rays might appear as relatively unobscured (type 1) in the optical.

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