On the relation between X-ray absorption and optical extinction in AGN

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ABSTRACT

According to the Unified Model of Active Galactic Nuclei (AGN), an X-ray unabsorbed AGN should appear as unobscured in the optical band (the so called type-1 AGN). However, there is an important fraction (10-30%) of AGN whose optical and X-ray classifications do not match. To provide insight into the origin of such apparent discrepancies, we have conducted two types of analysis: 1) a detailed study of the UV-to-near-IR emission of two X-ray low absorbed AGN with high optical extinction drawn from the Bright Ultra-Hard XMM-Newton Survey (BUXS); 2) a statistical analysis of the optical obscuration and X-ray absorption properties of 159 type-1 AGN drawn from BUXS to determine the distribution of dust-to-gas ratios in AGN over a broad range of luminosities and redshifts. We have determined the impact of contamination from the AGN hosts in their optical classification (detection or lack of detection of rest-frame UV-optical broad emission lines). This is an on-going project, but our preliminary results, reported below, are very promising.

THE BRIGHT ULTRA-HARD XMM-NEWTON SURVEY (BUXS)

The AGN analyzed in this work were selected from the **Bright Ultra-hard XMM-Newton Survey** (BUXS; Mateos et al. 2012). This is a flux-limited sample of 258 AGN detected at 4.5-10 keV energies with the XMM-Newton observatory. It is based on 381 high Galactic latitude (|b|>20º) observations. The objects have large X-ray fluxes **$f_{4.5\text{-}10\ keV}$>6× 10^{-14} erg/s/cm^{-2}**, and were detected in a total sky area of **44.43 deg^2**.

The **optical spectroscopic completeness is > 98 percent.** We have **good quality XMM-Newton X-ray spectra (> 100 counts) in the observed energy range from 0.25 to 10 keV.** The selection of sources in the 4.5–10 keV band allows to reduce the strong bias against heavily absorbed AGN affecting surveys conducted at softer energies. The selected AGN are sensitive to N_H columns up to the Compton-thick limit (log(N_H)~24 cm^{-2})

Low X-ray absorption in 2 AGN

Object	log(L_x (2-10 keV)) erg/s	Redshift	Counts (MOS+pn)	N_H (cm^{-2})	Optical classification
J000441.24 +000711.3	42.76	0.1067	2312	<6.7×10^{20}	Type-1.9 (SDSS)
J025218.60 -011746.3	41.25	0. 026	1534	$1.7_{-1.4}^{+2.0}$×10^{21}	Type-2 (6dF Survey)

Table 1: X-ray information about the selected objects and optical classification of the sources from public surveys.

We have good quality XMM-Newton X-ray spectra in the observed energy range from 0.25 to 10 keV for the two objects. The X-ray spectroscopic analysis was conducted with the XSPEC package. The best fit models are a power law plus black body emission for J000441.24+000711.3 and an absorbed power law for J025218.60-011746.3. We present UV-to-NIR high resolution spectra for both objects from VLT/XSHOOTER (Vernet et al. 2011). The observations were reduced using the public XSHOOTER pipeline version 2.3.0.

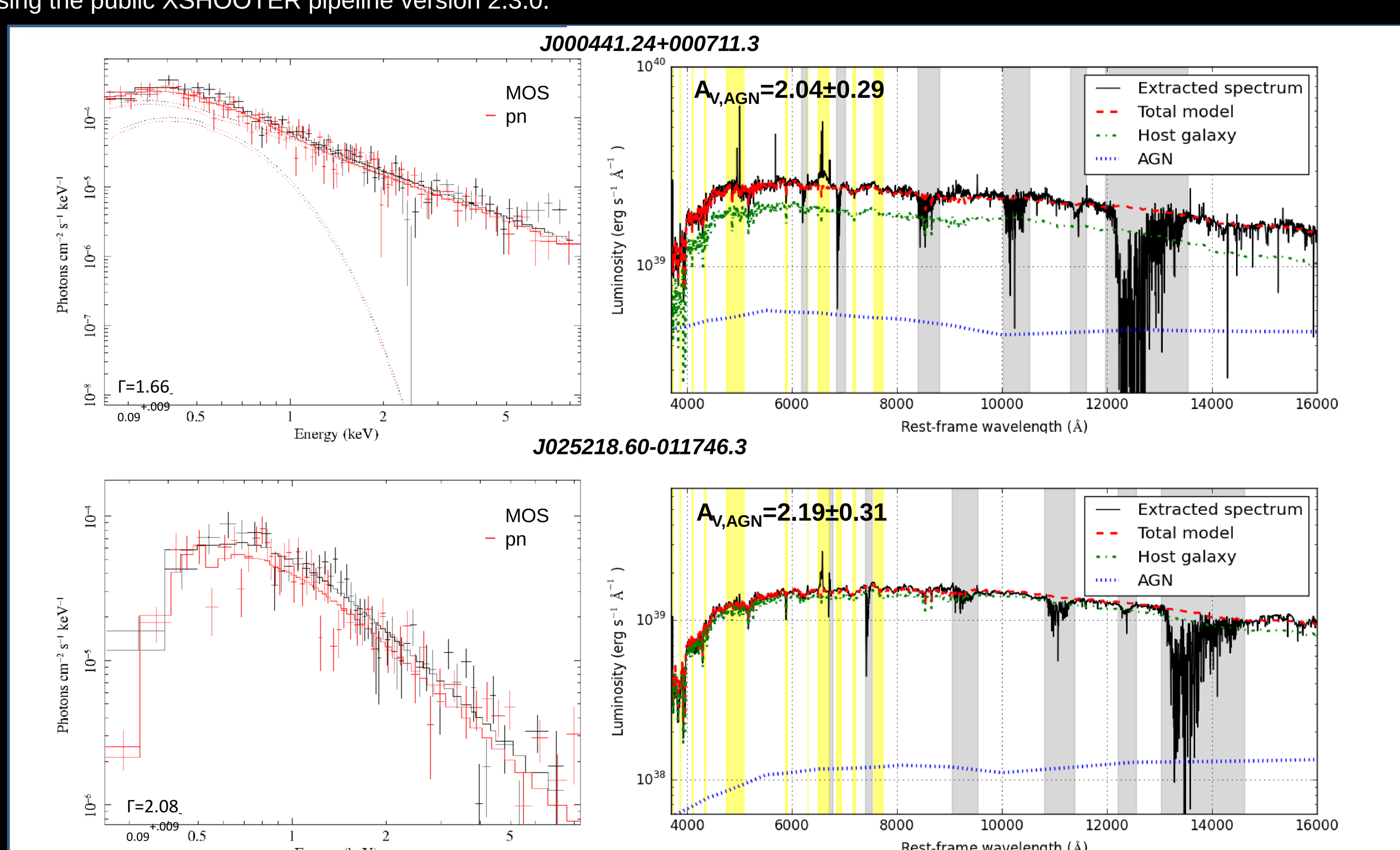


Figure 1: X-ray spectra (left) and UV-to-NIR spectra (right) for J000441.24+000711.3 (top) and J025218.60-011746.3 (bottom). In the X-ray spectra we plot the best-fit model with solid lines and the components with dotted lines. In the UV-to-NIR spectrum we plot the telluric absorption bands in gray and we plot zones removed from the fit due to AGN emission lines in yellow. Errors and upper limits are 68 per cent confidence.

To **decompose the extracted spectra into AGN and host galaxy emission** we used STARLIGHT (Cid Fernandes et al. 2005). We model the extracted spectrum with host galaxy emission, using SSP models from the Bruzual & Charlot library (Bruzual & Charlot 2003), and AGN emission modeled with a broken power law affected by nuclear extinction using the SMC model of Gordon (Gordon et al. 2003). We also added an additional extinction associated with the AGN hosts.

The Galactic relation for the dust-to-gas ratio is A_V/N_H=5.30×10^{-22} mag/cm^{-2}. **For J000441.24+000711.3 A_V/N_H>2.6×10^{-21} mag/cm^{-2}** (>5 times the Galactic ratio), **meanwhile for J025218.60-011746.3 A_V/N_H=$1.30_{-1.1}^{+1.8}$×10^{-21} mag/cm^{-2}** (6-0.6 times the Galactic ratio).

We compared the host galaxy stellar masses with the SMBH mass derived from the UV-to-NIR spectra. The software STARLIGHT gives the stellar mass of the host galaxy. To calculate the SMBH mass we used both the luminosity and FWHM of the Hα broad emission line (Greene et al. 2005). The obtained luminosity of the broad component of the Hα line is then corrected for both the nuclear extinction and the host galaxy extinction.

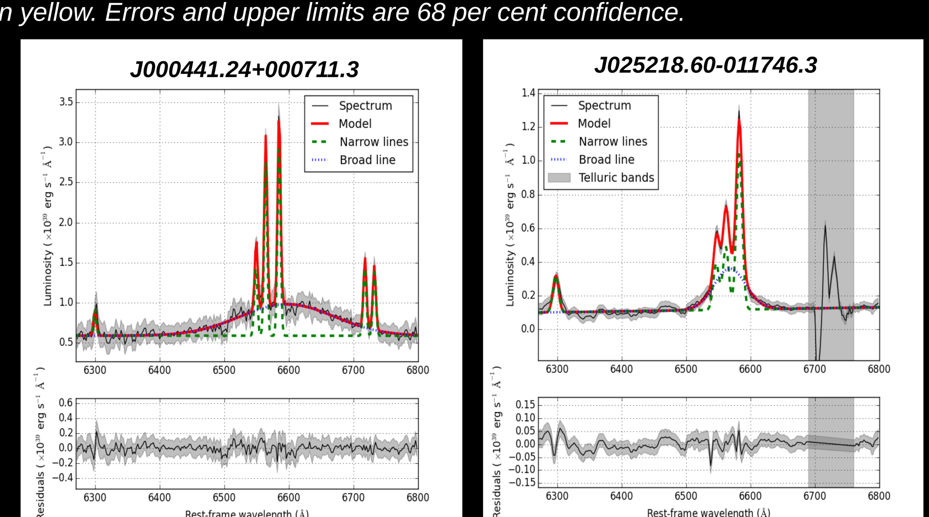


Figure 4: Spectrum of the nucleus of J000441.24+000711.3 (left) and J025218.60-011746.3 (right) Top: Hα region and its decomposition in narrow and broad lines. The emission lines are fitted with gaussian functions and the local continuum with a power law Bottom: Residuals of the fits. Errors are 68 per cent confidence.

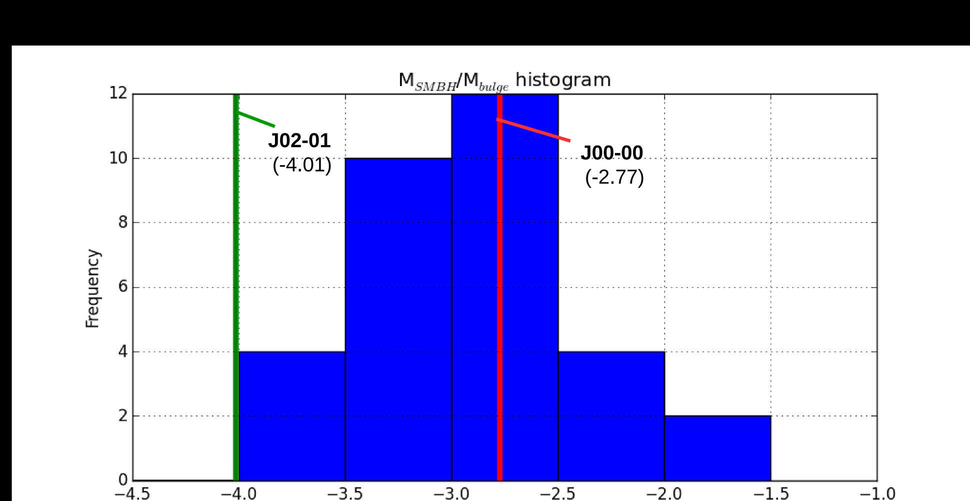


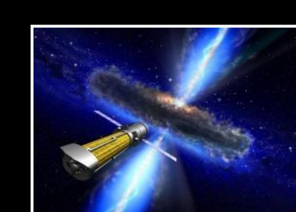
Figure 3: Histogram of log(M_{SMBH}/M_{bulge}) from Merritt & Ferrarese 2001). We see that J000441.24+000711.3 (red) falls in the centre of the distribution meanwhile J025218.60-011746.3 (green) deviates significantly from the central value.

Object	A_V/N_H (mag/cm^{-2})	log(M_{SMBH}/M_{bulge})
J000441.24+0000711.3	>2.61×10^{-21}	-2.77
J025218.60-011746.3	$1.30_{-1.1}^{+1.8}$×10^{-21}	-4.01
Standard values	5.30×10^{-22}	-2.90±0.45

Table 2: Results for the dust-to-gas and log(M_{SMBH}/M_{bulge}) *ratios*

An intrinsically different A_V/N_H explains better the discordant classification for J000441.24+000711.3, making the X-ray emission to be less obscured than in the optical range. **The black hole in J025218.60-011746.3 is smaller than expected in comparison with its host galaxy**, between 2 and 3 times the rms below the relation from Merritt & Ferrarese (2001). This may explain why the AGN emission is outshined by the host galaxy star light. In conclusion, for **J000441.24+000711.3 the discordance is explained by a different dust-to-gas ratio. For J025218.60-011746.3 the massive host makes the AGN signatures to be diluted by the host galaxy starlight.**

A_V/N_H in the type-1 sample



The objective of this work is to conduct a **statistical analysis of the X-ray absorption and the optical obscuration of the optically type-1 sample of the Bright Ultra-Hard XMM-Newton Survey (BUXS).** These sources are classified as type-1 based on the optical spectrum (SDSS or follow-up observations) if we detect a broad emission line.

The sample of type-1 AGN is composed by 159 objects, with 123 AGN with log(N_H)<21.6 and 31 with log(N_H)>21.6 cm^{-2} (see Fig. 4). There are 5 sources with the limit of 21.6 cm^{-2} within the errors. T**he type-1 sample** has a **~20% of sources that are X-ray absorbed.**

Properties	Range
log(L_x (2-10 keV))	42-46
z	0.05-3.00
Nº objects	159
Nº absorbed AGN	31-36

Table 3: Description of the BUXS type-1 sample.

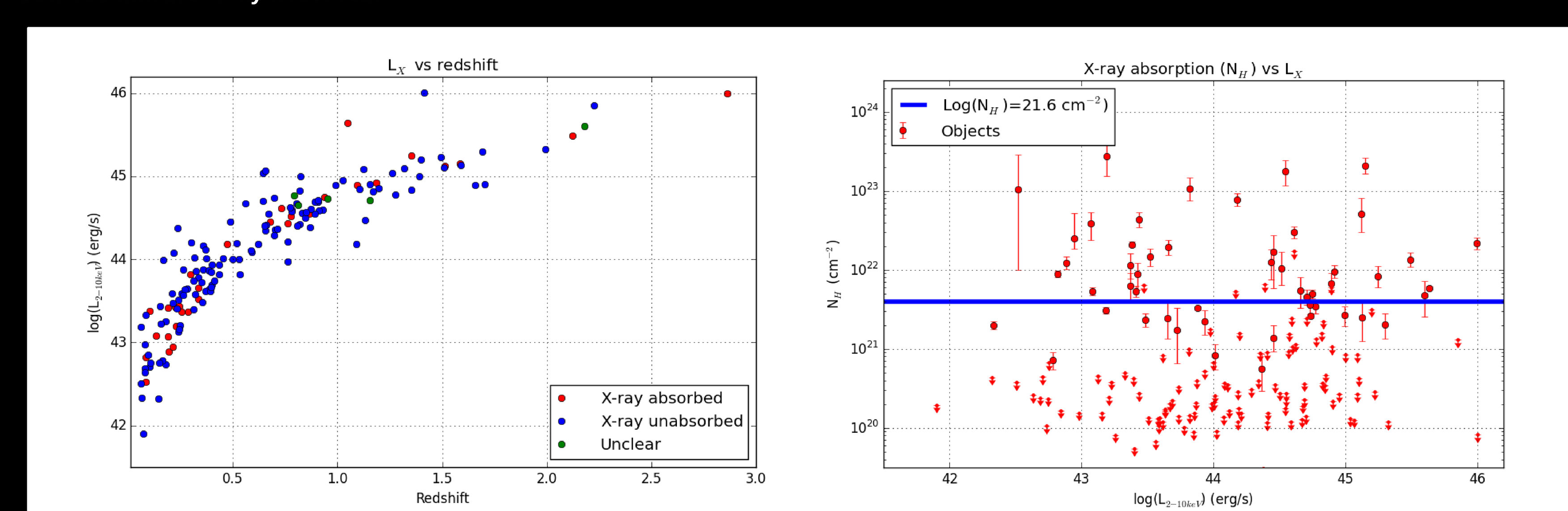


Figure 4: Log(Lx) vs redshift (left) and log(N_H) vs log(L_x) plots (right) for the BUXS type-1 sample. The values of the N_H are represented with 68 per cent confidence errors. If we can only derive a 68 per cent confidence upper limit to the N_H it is indicated with an arrow.

We fitted both the X-ray and the optical spectra to measure the X-ray absorption and the optical extinction respectively. **We fitted the X-ray spectra with a combination of different models to determine the shape of the direct and scattered continuum components** (modeled with power laws). **To derive the optical extinction first we fitted the SED to determine the host galaxy emission** in each source with the Bruzual & Charlot library (details in Mateos et al. 2015). On second term **we fit the optical spectra** with a model of host galaxy and AGN emission, the latter affected by nuclear extinction with the SMC model from Gordon et al (2003). We used the AGN template of Richards et al. (2006).

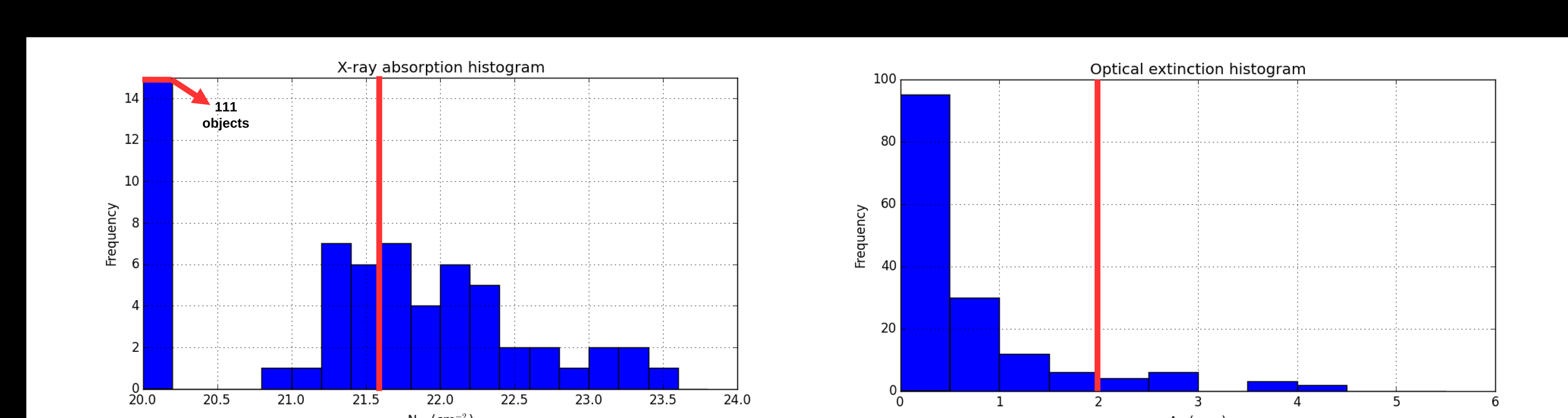


Figure 5: Histogram of X-ray absorption in terms of N_H (left) and histogram of optical extinction in terms of A_V (right) for the BUXS type-1 sample. We use the limit of log(N_H)=21.6 cm^{-2} (with a red line), the equivalent of A_V=2 mag for a Galactic dust-to-gas ratio (Caccianiga et al. 2008), to divide the sources between X-ray absorbed or not. We also put this limit in the A_V histogram with a red line.

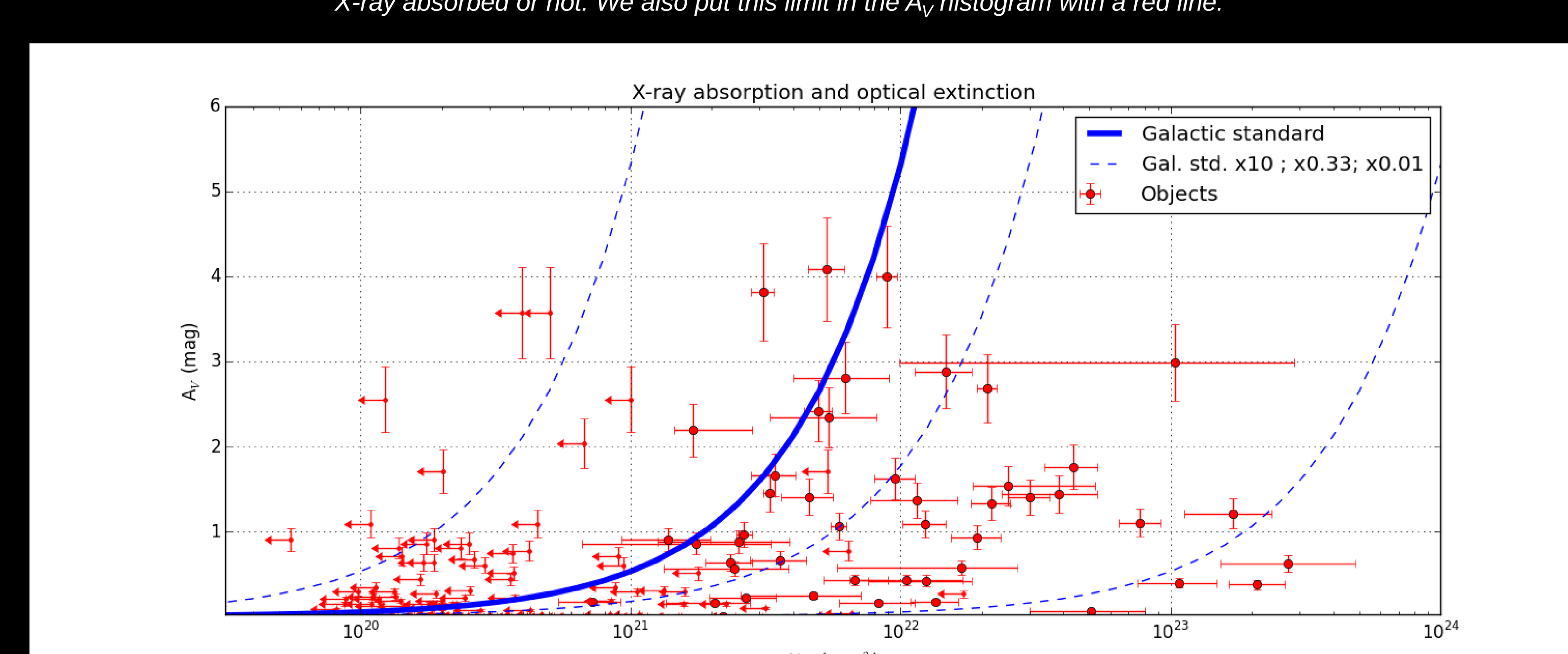


Figure 6: Dust-to-gas ratio for the BUXS type-1 sample. We represent here the plot of A_V vs N_H for our objects, with the 68 per cent confidence errors. If we can only derive a 68 per cent confidence upper limit to the N_H it is indicated with an arrow. The solid line represent the Galactic ratio and the dashed lines represents 10 times higher and 3 and 100 times lower than the Galactic relation.

The main finding of the preliminary results of the BUXS type-1 sample shows a range of the dust-to-gas ratios significantly wider than we previously thought. If compared with the Maiolino et al. (2001) results, whose the objects are found between 3 and 100 times below the Galactic relation, there are 4 objects that have an extreme discordance, as they are between 100 and 1000 times below the Galactic relation. We also found 6 objects with dust-to-gas ratios than more than ten times above the Galactic one.

CONCLUSIONS

The ~10-20% of AGN with discordant optical and X-ray classification are still an important challenge to the Unified Model of AGN. This is why we conducted this study with an unbiased sample like BUXS. From the detailed study of two low X-ray absorbed AGN with high optical extinction we can conclude that AGN with a discordant X-ray/optical classification do not represent an homogeneous class, as the cause of the observed discordance can be different. For J000441.24+000711.3 an intrinsically high dust-to-gas ratio is the most likely explanation for the observed properties. A change in the gas-to-dust ratio can misclassify an AGN, specially if it is in the range of intermediate AGN (log(N_H)~22 cm^{-2}). The optical spectrum of J025218.60-011746.3 is significantly diluted by the host galaxy light making the optical classification unreliable. The effect of dilution seems to be particularly important in this source due to the very low SMBH/host bulge mass ratio.

The statistical study shows that in the majority of the objects in our sample, the dust-to-gas ratio is compatible with the Galactic or lower. In comparison with the Maiolino et al. (2001) sample, whose AGN show values normally between 3 and 100 times below the Galactic relation, we obtain a wider range of ratios. Dust-to-gas ratios of AGN are not well known to date and play an important role in understanding AGN.

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The SDSS is managed by the Astrophysical Research Consortium for the Participating Institutions. The Participating Institutions are the American Museum of Natural History, Astrophysical Institute Potsdam, University of Basel, University of Cambridge, Case Western Reserve University, University of Chicago, Drexel University, Fermilab, the Institute for Advanced Study, the Japan Participation Group, Johns Hopkins University, the Joint Institute for Nuclear Astrophysics, the Kavli Institute for Particle Astrophysics and Cosmology, the Korean Scientist Group, the Chinese Academy of Sciences (LAMOST), Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Ohio State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.
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