

# UNVEILING THE DISTRIBUTION OF ABSORPTION IN THE AGN POPULATION

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## ABSTRACT

We use the very deep *XMM-Newton* observations in the CDF-S to measure the distribution of absorption in the AGN population. We describe the Monte Carlo method used to unveil the intrinsic properties of the AGN using their multi-band X-ray colours. The measured distribution of AGN in  $z$ ,  $L_X$  and  $N_H$  space is compared with the distributions predicted by a number of XLFs and absorption models. In contrast to other studies, we do not find any evidence that the absorption distribution is dependent on redshift or intrinsic luminosity.

## 1. INTRODUCTION

A large population of absorbed AGN are required to explain the hard spectrum of the extragalactic X-ray background. However, even though absorbed AGN outnumber their unabsorbed brethren by a factor of four in the local Universe (e.g. Risaliti et al., 1999, ApJ, 522, 157), the demographics of the population at higher redshifts are still poorly understood. The simple “unified” model of AGN attributes this absorption to a 1–100pc scale dusty torus surrounding the central black hole and accretion disk, where the degree of absorption seen by an observer is determined primarily by the angle at which an AGN is viewed. By measuring the distribution of absorption in the AGN population we can place constraints on the typical geometry of such a torus. In addition, we can test for the existence of a correlation between absorption and redshift and/or luminosity. Therefore, we have examined a sample of X-ray sources detected in the deep *XMM-Newton* observations of the *Chandra* Deep Field-South (CDF-S).

## 2. OBSERVATIONS AND SAMPLE SELECTION

The *XMM-Newton* data in the CDF-S consist of 500ks of observations, of which around 350ks is unaffected by background flares. This is the 2nd deepest *XMM-Newton* survey to date. We subdivide the full energy range of the EPIC cameras into four bands: 0.2–0.5, 0.5–2, 2–5, and 5–10 keV. We detect 299 reliable X-ray sources to a limiting flux of  $\sim 10^{-16}$  erg cm $^{-2}$  s $^{-1}$  in the 0.5–2 keV band. The entire field is covered by deep *Chandra*

imaging (Extended-CDF-S project; Lehmer et al., 2005, AJ, 129, 1), and the central region is covered by very deep (1Ms) *Chandra* observations (Giacconi et al., 2002, ApJS, 139, 639). For unambiguous optical identification, we adopt the high accuracy *Chandra* positions where possible. Extensive spectroscopic identification programs have been carried out in the CDF-S especially for optical counterparts of the *Chandra* sources, (e.g. Szokoly et al., 2004, ApJS, 155, 271; Zheng et al., ApJS, 155, 73Z). Almost the entire *XMM-Newton* field is also covered by the COMBO-17 survey (Wolf et al., 2004, A&A, 421, 913), which provides good photo- $z$  estimates for galaxies to  $R=24$ . We find that 86% (258/299) of the *XMM-Newton* detections have identified optical counterparts. Of these, 16 sources are stars, and 5 suffer from source confusion; these sources are removed from the sample.

## 3. DATA ANALYSIS AND RESULTS

We have used detailed simulations in order to understand the selection function and any biases inherent to the *XMM-Newton* observations (and the source searching algorithm). We couple X-ray luminosity functions with an empirical absorption distribution model to generate a random synthetic population of “input” AGN. The multi-band count-rates expected for each simulated AGN are then calculated according to an absorbed power-law plus reflection spectral model, taking into account the EPIC response. Simulated multi-band images are generated using the EPIC PSF together with the exposure maps and unresolved background of the real observations. We apply the source searching routine that is used on the real data in order to find “output” sources in these images. Each “output” source is matched to the appropriate “input” counterpart, allowing its output parameters (i.e. multi-band count rates), to be related to input parameters (i.e.  $z$ ,  $L_X$ , and  $N_H$ ). The simulation process is repeated for the equivalent of 2000 fields in order to populate densely  $z, L_X, N_H$  space. See Loaring et al. (2005, MNRAS, 362, 137), and Dwelly et al. (2005, MNRAS, 360, 1426), for a detailed description of this process. We use this library of simulated sources to find the most likely  $N_H$  of the AGN in our CDF-S sample. For each AGN, we select all those simulated sources having similar multi-band hardness ratios ( $HRs$ ), redshifts and full band count rates. The best estimate for the  $N_H$  of

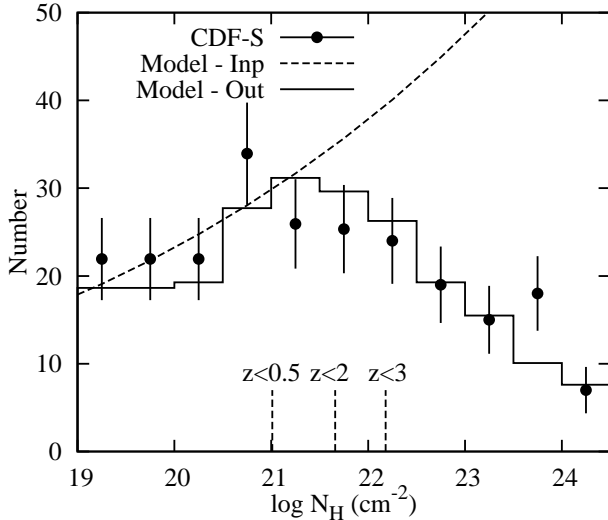


Figure 1. The distribution of absorption in the XMM-Newton CDF-S sample, compared to the prediction from the best fitting  $N_H$  distribution model (the  $\beta = 5$  absorption distribution, see text). We show the input model  $N_H$  distribution (before selection effects) as well as the recovered distribution in the simulated output population. Vertical dashed lines show the lowest value at which we can determine the absorbing column at a given redshift. All those sources which are determined to have a column lower than the limit for their redshift are divided equally between the bins lower than this  $N_H$  limit.

the real AGN is taken to be the modal “input”  $N_H$  of this subset of simulated sources. We have checked the fidelity of this method by using it to recover the known  $N_H$  of simulated sources. We find that for simulated sources at  $z < 2$ , and with  $N_H > 10^{21.5} \text{ cm}^{-2}$ , we are able to recover the input absorption reliably. At higher redshifts, absorption is shifted out of band, and so we are only able to place upper limits for moderately absorbed AGN. We use a similar method to deduce the “de-absorbed” intrinsic rest frame 2–10 keV luminosities of the sample. As before, we select all simulated sources having similar  $HRs$ , redshift, and full band count rate to the real AGN. The weighted median luminosity of these simulated objects is taken to be the best estimate of the intrinsic luminosity of the AGN. The scatter of the recovered values about the input values is typically less than 0.2dex. We compare the  $z, N_H, L_X$  distribution of the CDF-S sample with those predicted by a number of model  $N_H$  functions, coupled with the model XLF of Ueda et al. (2003, ApJ, 598, 886). We have compared the predictions of a range of absorption distributions including those of Ueda et al. (2003), Treister et al. (2004, ApJ, 616, 123), and Gilli et al. (2001, A&A, 366, 407), as well as a simple parameterisation where  $dN/d\log N_H \propto (\log N_H)^\beta$ ,  $\beta = 2, 5, \text{ or } 8$ . We fold these model populations through our Monte Carlo process, and then estimate the output  $N_H$  and  $L_X$  of the simulated sources in the same way as for the AGN in the CDF-S sample. The  $N_H$  and  $L_X$  distributions found in the CDF-S sample are compared to the predictions made by the best matching model ( $\beta = 5$ ) in figures 1 and 2.

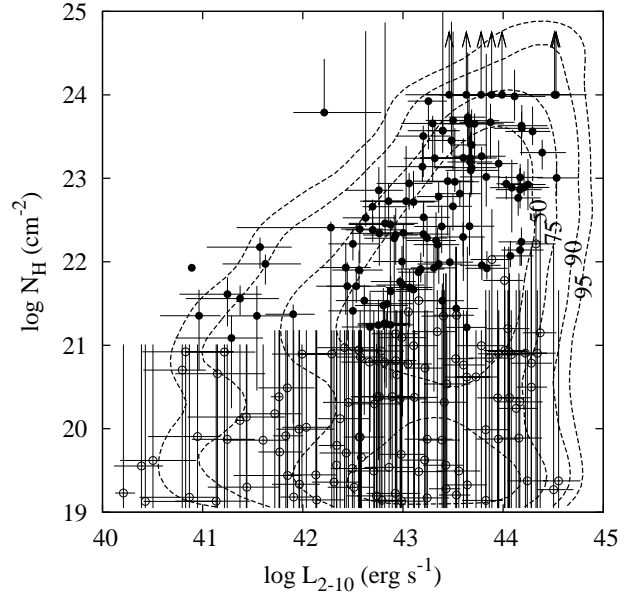


Figure 2. The 2–10 keV  $L_X$  vs  $N_H$  distribution of the CDF-S sample (points). Sources for which we can only determine upper limits on  $N_H$  are shown with open symbols. Contours show the distribution predicted by the  $\beta = 5$  model (contour levels are set to include 50%, 75%, 90% and 95% of the model sources).

#### 4. DISCUSSION

We have demonstrated a Monte Carlo method for accurately estimating the X-ray absorption and intrinsic luminosity in a sample of optically identified AGN observed with XMM-Newton. Our CDF-S sample reaches to high redshifts ( $z < 4$ ), and spans the knee of the luminosity function ( $L^* \sim 10^{44} \text{ erg s}^{-1}$ ). We find that  $\sim 35\%$  of the identified sources are heavily absorbed AGN ( $\log N_H > 22$ ). Our  $N_H$  estimation method finds evidence for moderate absorption ( $21 < \log N_H < 22$ ) in  $\sim 70$  AGN; Obscuration models where AGN are surrounded by uniformly dense tori do not predict large numbers of these intermediately absorbed objects. The model which best reproduces the  $N_H$  distribution of the CDF-S sample is a simple parametrisation, where the number of AGN having absorption per unit  $\log N_H$  is proportional to  $(\log N_H)^\beta$  (the  $\beta = 5$  model). After allowing for selection effects in the sample, we see no strong dependence of the  $N_H$  distribution on either redshift or luminosity in the ranges probed by this sample. When compared to the three dimensional  $z, L_X, N_H$  distribution of the sample, the best matching  $N_H$  distribution was again the  $\beta = 5$  model, which matched with 3-D KS probability  $P_{3D-KS} = 0.01$ . The main source of the disparity is the redshift distributions: the sample is strongly peaked at  $z \sim 0.7$  (e.g. Gilli et al. 2003, ApJ, 592, 721), a feature not reproduced by the model XLF. This work highlights the importance of high quality, broad-band X-ray spectral information in determining the  $N_H$  distribution of faint sources, and the need to account rigorously for selection effects.