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Spectral properties from XMM-Newton observation of Chandra Deep Field South sources

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Abstract. We present results of the X-ray spectral analysis of the ∼370 ksec deep survey obtained with XMM-Newton on the Chandra Deep Field South (CDFS). Using sample of 127 sources with redshift identifications and with a raw count limit of 100 (pn detector) we explored both the physical properties of individual sources, and the general properties of two AGN classes. The corresponding flux limits in the (0.5–2) and (2–10) keV bands are 1 $\times 10^{-16}$ and 9 $\times 10^{-16}$ erg cm^{-2} s^{-1}, respectively. The average photon index is $\Gamma \sim 1.9$ and $\Gamma \sim 1.8$ for type-1 AGN and type-2 AGN, respectively. Although the properties of the spectra of more that 90% of AGN are in good agreement with the unified model, a fraction of 'atypical' objects (absorbed type-1 and unabsorbed type-2 AGN) was detected.

Keywords. Surveys – Galaxies: active – *(Galaxies:)* quasars: general– X-ray: galaxies – galaxies: nuclei– *(Cosmology:)* diffuse radiation.

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1. Introduction

The X-ray background (XRB) has been a matter of intense study since its discovery by Giacconi *et al.* (1962). Now it is clear that at energies above ∼0.5 keV the XRB is made up of the summed emission from point sources, principally active galactic nuclei (AGN) along with some contribution at soft X-ray energies from thermal emission of galaxy clusters and stellar processes in normal galaxies. Since the XRB is mostly associated with point sources, the general interest has moved to accurately constrain the physical and evolutionary properties of these different classes of X-ray sources. To this aim, statistically significant samples of AGN that cover a range of redshift and luminosity from the deep and shallow surveys have been formed. This information makes the data an invaluable resource for revealing various key issues such as physical and evolutionary properties of AGN, and finally can be used to investigate, whether the unified model holds.

The *Chandra Deep Field South* (CDFS) is an area in the sky with a low Galaxy absorbing column density of 8.9$\times$ 10^{19} cm^{-2} (Dickey & Lockman 1990). The CDFS has been studied intensively by means of a megasecond dataset from the Chandra Observatory (e.g. Giacconi *et al.* (2002), Tozzi *et al.* (2005), and references therein). This field was observed also with XMM-Newton (370 ksec good exposure; Streblyanska *et al.* 2003) and re-observed with Chandra (∼250 ksec in each 4 pointings; Lehmer *et al.* 2005). The CDFS is one of the sky regions best studied not only in the X-ray band but also in the other wavelengths (radio, optical, infrared). In addition, the CDFS is one of the best fields with available spectral and photometric redshift information through different follow-ups with the VLT (e.g. Szokoly *et al.* (2004)) and some other ground-based imagings (e.g. Wolf *et al.*

2004). As a result, in the entire field of 1Ms Chandra observation only 4 objects, out of 347, have no identification (e.g. Zheng *et al.* (2004) and Mainieri *et al.* (2005)). This completeness made CDFS one of the reference fields for studies of distant normal and active galaxies, clusters of galaxies and even faint Galactic stars.

2. Data reduction and X-ray source list

The CDFS (RA 3:32:28 and DEC -27:48:30 [J2000]) XMM-Newton observation contains ∼370 ksec of clean data. The pn and MOS data were preprocessed by the *XMM Survey Scientist Consortium* with the XMM standard Science Analysis System (SAS, version 5.3.3) routines, using the latest calibration data. The merged images (pn+MOS) in the three energy bands were simultaneously searched for sources using tasks `emldetect` and `eboxdetect`. We detect 363 sources (likelihood value above 8) in pn+MOS1+MOS2. The corresponding flux limits in the (0.5–2) and (2–10) keV bands are 1×10^{-16} and 9×10^{-16} erg cm^{-2} s^{-1}, respectively.

The majority of the sources in our datasets have poor counting statistics, however we were able to construct a large sample of AGN for accurate source-by-source X-ray spectral analysis. In order to use χ^2 minimization technique and obtain reliable fits, we choose the sources with more than 100 counts (pn detector) and with spectroscopic or photometric redshift information. All these sources are contained in the 1 Ms Chandra catalogue, which allowed us to made comparison between these two datasets. The spectral analysis for corresponding sources from the Chandra observation is described in Tozzi *et al.* (2005) where analysis of 321 (out of 346) X-ray sources is presented. The comparison between XMM-Newton and Chandra datasets with complete information about spectral properties of analysed sources will be presented in Streblyanska *et al.* (in preparation).

The spectroscopic identification from VLT follow up is discussed in details in Szokoly *et al.* (2004). The dominant population in CDFS (as in other deep surveys) is a mixture of obscured (type-2) and unobscured (type-1) AGN with a small fraction of normal galaxies and groups/clusters of galaxies. We concentrated our attention on the analysis of point sources, while a complete analysis of extended objects and their properties will be presented in Finoguenov *et al.* (in preparation). For some of the sources we used photometric redshifts from Zheng *et al.* (2004) and Mainieri *et al.* (2005).

Finally, we selected the sample of 127 X-ray sources with spectroscopic or photometric identification. Our complete sample includes 78 type-1 AGN, 39 type-2 AGN and 10 galaxies.

3. Results from spectral fitting

We performed a detailed spectral analysis with different models in order to investigate the complexity of AGN spectra, for example soft excess, iron line, absorption edge, etc. We fit pn and MOS spectra simultaneously in the 0.2–10 keV band using appropriate response matrixes (`arf` and `rmf`).

Analysis of the soft component is very important in terms of properly modeling of the absorption and the power law slope. For some of our type-2 AGN, the detection of $N_{\rm H}$ and spectral shape were only significant after taking into account the soft excess as a spectral component. We detect a clear soft component in both type-1 (3 sources) and type-2 (8 sources) AGN, although the origin of this component believed to be different for different AGN classes. In type-2 AGN we used a scattering or partial covering model (nuclear radiation scattered by warm medium/leaking through the absorber) in order to explain the soft part of the spectrum, while in type-1 AGN we modelled the soft excess

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with a blackbody (thermal emission from the accretion disk, but other interpretations are also possible). The detected temperature in type-1 AGN range between 21–110 eV. The average covering fraction in the type-2 AGN is $0.91^{+0.05}_{-0.06}$.

The properties of the spectra of most AGN are in good agreement with the unified model, which postulates obscuration for type-2 and no absorption for type-1 AGN. A fraction of 'unusual' objects (absorbed type-1 and unabsorbed type-2 AGN) was, however, detected. Similar 'atypical' objects have been discovered in several other deep/shallow surveys using statistically significant samples of sources, e.g. HELLAS2XMM (Perola *et al.* 2004), ChaMP (Silverman *et al.* 2005), Lockman Hole (Mateos *et al.* 2005) etc. These authors reported that 6–10% of detected type-1 AGN are absorbed, most of them are luminous ($L_X > 10^{44}$ ergs s^{-1}) and high-z objects, implying a decoupling between optical and X-ray properties at high luminosities and redhifts. This difference between the optical and X-ray classifications can be explained either by a gas-to-dust ratio and/or the chemical composition significantly different from that of the Galactic interstellar gas (e.g. Akiyama *et al.* 2000). From a purely empirical side, one should not forget that variability may also play a role. The most favourable explanation for unabsorbed type-2 AGN is that they are Compton-thick sources. If intrinsic absorption of these sources exceeds 10^{24} cm^{-2}, the optical depth for Compton scattering equals unity, and the direct nuclear emission is completely blocked in both the soft and hard bands. In this situation only the radiation reflected by the cold medium/scattered by the ionized material can reach the observer, and therefore spectra will be without any apparent absorption. The representative spectra of some of AGN are shown in Figure 1.

The weighted mean value of Γ for total sample is 1.86±0.03. The average photon index is $\Gamma \sim 1.9$ and $\Gamma \sim 1.8$ for type-1 AGN and type-2 AGN, respectively. We derive the distributions of spectral index, intrinsic absorption, flux and luminosity, as well as investigate dependences between these parameters. We find no real correlation between Γ and the intrinsic absorption column N_H density. The slight correlation between absorption and lower values of the continuum is mostly an effect of the low statistic of our data. Taking into consideration this fact, our results confirm the idea that the clear separation between the two AGN populations is mostly due to differences in the absorption column density, not in Γ. These results are consistent with the unified scheme of AGN, which links classifications based on optical spectra and properties of the X-ray spectra. We also find no evolution of Γ and N_H with redshift (see Figure 2).

4. Conclusions

Using optical source identification and redshift information, we explored both the physical properties of individual sources, and the general properties of two AGN classes, using a statistically significant sample of 127 sources with redshift identifications. One of the purposes of our analysis was to investigate whether the unified model of AGN holds.

More than 90% of the source spectra are in agreement with the unified model, however a fraction of 'atypical' sources (absorbed type-1 AGN and unabsorbed type-2 AGN) was also discovered. Most of these 'atypical' objects have good signal-to-noise ratio which does not allow us to ascribe these properties to the poor spectra quality. The observed mismatch between X-ray and optical properties may be explained by a difference in the physical conditions surrounding the emission regions.

Most AGN spectra required only an (un)absorbed power law model, however we detect a fraction of the sources with additional spectral components such as a soft excess (11 sources) and iron line (7 sources).

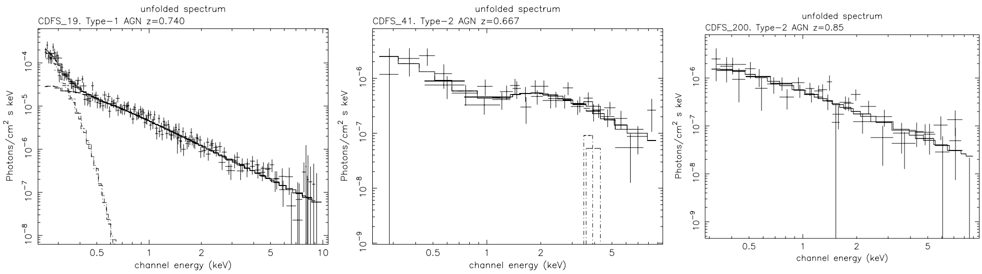

Figure 1. The unfolded model X-ray spectra representative of the different classes of objects in the CDFS. The source numbers refer to the Chandra catalogue from Giacconi *et al.* (2002). From the left to the right: type-1 AGN with the soft excess, type-2 AGN with the soft component and iron line, 'atypical' unabsorbed type-2 AGN.

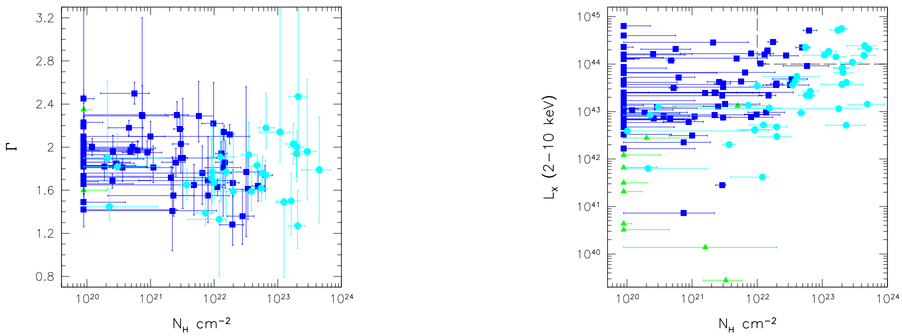

Figure 2. Left: The rest-frame power law photon indices Γ versus absorbing column densities $N_{\rm H}$ for the analyzed sample. Solid blue squares and cyan circles refer to type-1 AGN and type-2 AGN, respectively. Triangles show the galaxies. Γ for identified objects range from 1.4 to 2.5, with the majority of the sources clustering around 1.9. **Right:** Unabsorbed rest-frame luminosities in the hard (2–10) keV band versus the detected absorption. Upper right corner outlined by the dashed line shows the locus of type-2 QSO (defined as sources with $L_X > 10^{44}$ ergs s^{-1} and $N_{\rm H} > 10^{22}$ cm^{-2}).

No obvious correlations between spectral continuum and absorption or between Γ, $N_{\rm H}$ and redshift are found.

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Discussion

McBreen: How many of your sources are unabsorbed Type II AGN?

Streblyanska: In our sample we found 3 unabsorbed type-2 AGN. However only in one case we have enough statistics to confirm this result. Other two sources show indications for unabsorbed spectra, but due to the low statistics there could be other explanations (e.g. background contamination).