The search for heavily obscured AGN in the Chandra Deep Fields

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C. Vignali[1,2], M.E. Dalla Mura[1], I. Delvecchio[3], G. Lanzuisi[1,2], F. Vito[4,5], F. Pozzi[1,2], C. Gruppioni[2]

[(1) Physics and Astronomy Department, University of Bologna; (2) INAF−Bologna Observatory; (3) Department of Physics, University of Zagreb; (4) Department of Astronomy & Astrophysics, The Pennsylvania State University; (5) Institute for Gravitation and the Cosmos, The Pennsylvania State University]

Abstract In the last decade, multi-wavelength surveys have allowed the discovery of a large number of heavily obscured Active Galactic Nuclei (AGN), including the most elusive Compton-thick (CT, $N_H > 10^{24}$ cm^{-2}) AGN, largely at low redshift. Probing high-redshift CT AGN is often limited by the paucity of photons in the X-ray band. Here we use the 7Ms and 2Ms data in the Chandra Deep Field South (CDF-S) and North (CDF-N), respectively, to shed light on the X-ray spectral properties of a sample of 14 (CDF-S) and 4 (CDF-N) obscured AGN candidates at z≈0.1−3.5. These sources were selected as having **a predicted X-ray luminosity**, derived from the bolometric luminosity (L_{BOL}, from SED-fitting decomposition analysis), **much higher than that actually observed** (not corrected for absorption), suggesting the presence of **strong obscuration**. Using state-of-the-art torus modeling to fit the X-ray data, we found that **13/18 sources are obscured by $N_H > 10^{23}$ cm^{-2}, with three AGN being likely CT.**

Selection of obscured AGN candidates

Starting from the work of Delvecchio et al. (2015), based on *Herschel*-selected galaxies in the GOODS and COSMOS fields and characterized via SED-fitting decomposition (using the SED3FIT code; see Berta et al. 2013), we selected 64 (CDF-S) and 58 (CDF-N) sources with X-ray detections and significant AGN emission in the mid-IR (see **Fig. 1**). Of these, **14** (**CDF-S**) and **4** (**CDF-N**) sources at **z≈0.1−3.5** (15/18 with spectroscopic redshifts) have a 2−10 keV luminosity predicted from the L_{BOL} (SED fitting) − assuming the bolometric correction $k_{BOL}=L_{BOL}/L_{2-10keV}$ of Marconi et al. (2004) − a factor of >10 higher than that measured. We ascribe the difference to the presence of obscuring matter. A similar method was adopted in the COSMOS field by Lanzuisi et al. (2015) to pick up the most obscured ($N_H > 10^{25}$ cm^{-2}) AGN in that field. We note that this is not a complete selection of obscured AGN; this work is meant to find heavily obscured AGN up to high redshift with sufficient statistics for a proper X-ray spectral analysis (see also Del Moro et al. 2016).

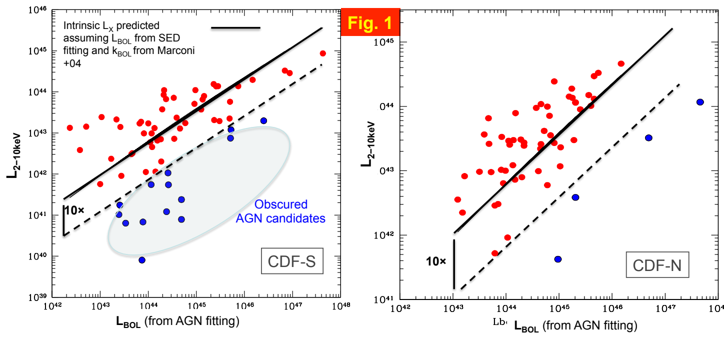


Fig. 1 Observed X-ray luminosity vs. L_{BOL} for the 64 (CDF-S, *left panel*) and 58 (CDF-N, *right panel*) *Herschel*-selected sources with significant AGN emission in the mid-IR and X-ray detection. The straight line indicates the predicted X-ray luminosity obtained using L_{BOL} (from SED fitting) and $k_{BOL}=L_{BOL}/L_{2-10keV}$ from Marconi et al. (2004). Our obscured AGN candidates (blue points, 14 in the CDF-S and 4 in the CDF-N) are those with a measured X-ray luminosity at least 10 times below (dashed line) the prediction.

X-ray spectral analysis results

We performed X-ray spectral analysis for the 18 sources reported above. The median number of net counts in the observed-frame 0.5−7 keV band is 100 in the CDF-S and 50 in the CDF-N. We started with simple phenomenological models and then adopted BNtorus (Brightman & Nandra 2012) and MYTorus (Murphy & Yaqoob 2009) models to account properly for all the components expected in obscured AGN; these models assume a toroidal geometry for the reprocessor, and reflection, transmission and scattering are self-consistently included. Thirteen sources (10 in the CDF-S and 3 in the CDF-N) have column densities above 10^{23} cm^{-2}, one has a loose upper limit; in particular, **three sources have a flat X-ray slope and an intense (EW>1 keV) neutral iron line** (**Fig. 2**), strongly suggestive of **CT obscuration**. The intrinsic rest-frame 2−10 keV luminosity are in the range 10^{42} − 10^{46} erg/s, with the exception of four sources at $L_X << 10^{42}$ erg/s whose emission can be mostly ascribed to star-formation processes (e.g., Ranalli et al. 2003). These objects are the least obscured in the current sample ($N_H < 10^{22}$ cm^{-2}); their original selection can be due to degeneracies in the SED fitting with model templates. Despite these few cases, our X-ray spectral analysis confirms the overall goodness of the adopted selection method (i.e., luminous AGN-related mid-IR emission coupled with a low X-ray flux).

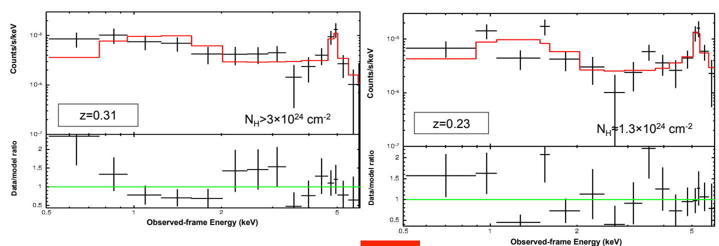
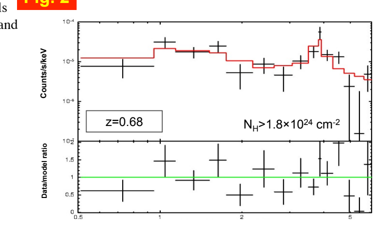


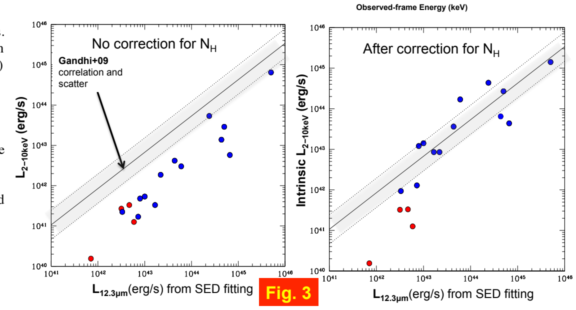
Fig. 2 X-ray spectra (*top panels*) and data/model residuals (*bottom panels*) for the three sources (two in the CDF-S and one in the CDF-N) which are characterized by heavy obscuration and a strong (EW>1) iron Kα line.



Mid-IR vs. X-ray emission

We finally checked the location of our sources in the $L_{2-10keV}$ vs. $L_{12.3\mu m}$ plot before and after correcting the X-ray luminosity for the measured absorption. The $L_{12.3\mu m}$, related to the AGN component obtained from the SED fitting, may be considered a proxy of the intrinsic strength of the AGN, as shown by the mid-IR vs. hard X-ray correlation of Gandhi et al. (2009; see also Asmus et al. 2015). **Once the correction for obscuration is applied, most of the sources move closer to the expected relation** (see blue points in **Fig. 3**).

Fig. 3 X-ray luminosity vs. $L_{12.3\mu m}$ for the sources with $N_H > 10^{23}$ cm^{-2} (blue points) and those $N_H < 10^{23}$ cm^{-2} (red points). (*Left panel*) The X-ray luminosity has not been corrected for the measured absorption. Once the correction is applied, most of the obscured sources fall in the expected region (*right panel*).

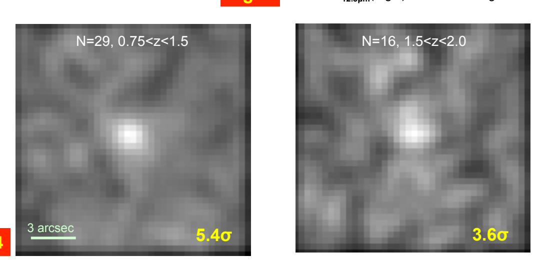


What's next

We used the deepest Chandra 7Ms observations of the CDF-S (Luo et al. 2017) to stack ≈70 X-ray undetected obscured AGN candidates located in the inner 7.8 arcmin of the CDF-S, selected as described above, all with spectroscopic z. A preliminary analysis reports the strongest signal (5.4σ) in the soft band from 29 sources at z=0.75−1.5 (see **Fig. 4**, left panel); significant (3.6σ) stacked signal is also present for the sample of 16 objects at z=1.5−2.0. Both signals are likely ascribed to obscured accretion and star formation. Further analysis to define the nature of the stacked signal and focused in the 2−10 keV band is ongoing.

Fig. 4 X-ray stacked signal in the soft band from 29 sources at z=0.75−1.5 (*left panel*) and 16 sources at z=1.5−2 (*right panel*). These sources were selected similarly to the obscured AGN candidates described above but are individually X-ray undetected in the 7Ms CDF-S exposure (Luo et al. 2017).

Fig. 4



References: • Asmus D. et al. 2015, MNRAS, 454, 766; •Brightman M., Ueda Y., 2012, MNRAS, 423, 702; •Del Moro A. et al., 2016, MNRAS, 456, 2105; •Delvecchio I. et al., 2015, MNRAS, 449, 373; •Gandhi P. et al., 2009, A&A, 502, 457; •Lanzuisi G. et al., 2015, A&A, 578, A120; •Luo B. et al., 2017, ApJS, 228, 2; •Marconi A. et al., 2004, MNRAS, 351, 169; •Murphy K.D., Yaqoob T., 2009, MNRAS, 397, 1549; •Ranalli P., Comastri A., Setti G., 2003, A&A, 399, 39. The SED3FIT code is available at http://cosmos.astro.caltech/page/other-tools.