X-ray Bright Optically Inactive Galaxies in XMM-Newton/SDSS fields: more diluted than absorbed?

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ABSTRACT
We explore the properties of X-ray Bright Optically Inactive Galaxies (XBONG) detected in the 0.5-8 keV spectral band in 20 public XMM-Newton fields overlapping with the SDSS. We constrain our sample to optically extended systems with log \( f_X/f_{opt} > -2 \) that have spectroscopic identifications available from the SDSS \((r < 19.2 \text{ mag})\). The resulting sample contains 12 objects with \( L_X(0.5-8 \text{ keV}) = 5 \times 10^{41} - 2 \times 10^{44} \text{ erg s}^{-1} \) in the redshift range \( 0.06 < z < 0.45 \). The X-ray emission in four cases is extended suggesting the presence of hot gas associated with a cluster or group of galaxies. The X-ray spectral fits show that two additional sources are best fit with a thermal component emission \((kT \sim 1 \text{ keV})\). Three sources are most likely associated with AGN: their X-ray spectrum is described by a steep photon index \( \Gamma \sim 1.9 \) typical of unobscured AGN while, they are very luminous in X-rays \( (L_X(0.5-8 \text{ keV}) \approx 10^{41} - 10^{44} \text{ erg s}^{-1}) \). Finally, three more sources could be associated with either normal galaxies or unobscured Low Luminosity AGN \((L_X < 10^{42} \text{ erg s}^{-1})\). We find no evidence for significant X-ray absorbing columns in any of our XBONGs. The above suggest that XBONGs, selected in the total 0.5-8 keV band, comprise a mixed bag of objects primarily including normal elliptical galaxies and type-1 AGN whose optical nuclear spectrum is probably diluted by the strong stellar continuum. Nevertheless, as our sample is not statistically complete we cannot exclude the possibility that a fraction of optically fainter XBONG may be associated with heavily obscured AGN.

Key words: Galaxies: active – Quasars: general – X-rays: general

1 INTRODUCTION
Deep Chandra surveys have resolved the bulk of the X-ray background in both the soft and the hard energies ( Mushotzky et al. 2000; Brandt et al. 2001; Giacconi et al. 2002; Alexander et al. 2003). A striking result is that these surveys do not find a single dominant population of heavily obscured AGNs, predicted by the X-ray background population synthesis models. On the contrary a heterogeneous population of sources is detected comprising a mix of (i) BL AGN (QSOs and Seyfert-1 galaxies), (ii) narrow emission line AGN, (iii) optically faint sources \((I > 24 \text{ mag})\) and (iv) 'passive' galaxies with absorption line optical spectra. The latter class of sources, frequently dubbed X-ray Bright Optically Inactive Galaxies (XBONGs), shows no sign of AGN activity in their optical spectra \((e.g. \text{ no emission lines})\), while the X-ray luminosity is large enough \((\gtrsim 10^{44} \text{ erg s}^{-1})\) that is hard to reconcile without invoking the presence of AGN activity \((Fiore et al. 2003; Hornschemeier et al. 2001; Barger et al. 2001)\). Although this class of sources has been detected in previous low resolution X-ray missions \((Elvis et al. 1981; Griffiths et al. 1995; Moran et al. 1996; Blair, Georgantopoulos & Stewart 1997)\) it is only recently that they have received much attention. This interest has been initiated by the suggestion that these sources host heavily obscured AGNs \((e.g. \text{ Comastri et al. 2002})\) and therefore, they may be the missing link between observations and model predictions. Indeed, a large fraction of completely hidden AGNs may be hosted by optically normal galaxies, partially explaining the scarcity of obscured AGN in deep X-ray surveys \((\text{Comastri et al. 2002})\).

Alternatively, the lack of optical emission lines can be explained if the nuclear component is outshined by the strong stellar continuum \((e.g. \text{ Severgnini et al. 2003})\). The X-ray spectra provide an invaluable tool for discriminating between the above possibilities. Unfortunately, the sources detected in the deep Chandra fields are in general too faint to allow detailed X-ray spectral analysis.

Therefore, it is important to find nearby, bright examples of XBONGs in wide angle relatively shallower surveys. Wide area coverage is difficult to achieve with the Chandra observatory due its limited field-of-view. On the contrary, XMM-Newton with 4 times larger field-of-view provides an ideal platform for such a study. In this paper we
exploit the capabilities and the large volume of archival data of the XMM-Newton to serendipitously identify XBONGs in public fields selected to overlap with the Sloan Digital Sky Survey (SDSS; York et al. 2000). This is to exploit the superb and uniform 5-band optical photometry and spectroscopy available in this area. Throughout this paper we adopt $H_0 = 65 \, \text{km} \, \text{s}^{-1} \, \text{Mpc}^{-1}$ and $\Omega_M = 0.3, \Omega_L = 0.7$.

2 THE DATA

2.1 The SDSS data

In this paper we use XMM-Newton archival observations with a proprietary period that expired before September 2003 and that overlap with the first data release of the SDSS (DR1; Stoughton et al. 2002). The SDSS is an ongoing imaging and spectroscopic survey that aims to cover about 10000 deg$^2$ of the sky. Photometry is performed in 5 bands (ugriz; Fukugita et al. 1996; Stoughton et al. 2002) to the limiting magnitude $g \approx 23$ mag, providing a uniform and homogeneous multi-color photometric catalogue. The SDSS spectroscopic observations will obtain spectra for over 1 million objects, including galaxies brighter than $r = 17.7$ mag, luminous red galaxies to $z \approx 0.45$ and colour selected QSOs (York et al. 2000; Stoughton et al. 2002).

2.2 The XMM-Newton data

The XMM-Newton archival observations used here have the EPIC (European Photon Imaging Camera; Strüder et al. 2001; Turner et al. 2001) cameras as the prime instrument operated in full frame mode. For fields observed more than once with the XMM-Newton we use the deeper of the multiple observations. The total of 20 XMM-Newton fields used here are listed in Table 1.

The X-ray data have been analysed using the Science Analysis Software (SAS 5.4). The event files produced by the XMM-Newton Science Center data reduction pipeline were screened for high particle background periods by rejecting time intervals with 0.5-10 keV count rates higher than 30 and 15 cts/s for the PN and the two MOS cameras respectively. The PN and MOS good time intervals for these pointings are shown in Table 1. The differences between the PN and MOS exposure times are due to varying start and end times of individual observations. Only events corresponding to patterns 0–4 for the PN and 0–12 for MOS have been kept.

In order to increase the signal-to-noise ratio and to reach fainter fluxes the PN and the MOS event files have been combined into a single event list using the MERGE task of SAS. Images have been extracted in the spectral bands 0.5–8 (total), 0.5–2 (soft) and 2–8 keV (hard) for both the merged and the individual PN and MOS event files. We use the more sensitive (higher S/N ratio) merged image for source extraction and flux estimation, while the individual PN and MOS images are used to calculate hardness ratios. This is because the interpretation of hardness ratios is simplified if the extracted count rates are from one detector only. Exposure maps accounting for vignetting, CCD gaps and bad pixels have been constructed for each spectral band. In the present study the source detection is performed on the 0.5–8 keV image using the EWAVELET task of SAS with a detection threshold of 5σ. In this paper we only consider sources with offaxis angles < 13.5 arcmin and therefore the total surveyed area is about 3.14 deg$^2$. A total of 1286 X-ray sources have been detected to the limit $f_X(0.5–8 \, \text{keV}) \approx 2 \times 10^{-15} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$. About 10 per cent of the total survey area is covered at the flux limit $f_X(0.5–8 \, \text{keV}) \approx 3 \times 10^{-15} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$. This fraction increases to about 50 per cent at $\approx 7 \times 10^{-15} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$.

Count rates in the merged (PN+MOS) images as well as the individual PN and MOS images are estimated within an 18 arcsec aperture. For the background estimation we use the background maps generated as a by-product of the EWAVELET task of SAS. A small fraction of sources lie close to masked regions (CCD gaps or hot pixels) on either the MOS or the PN detectors. This may introduce errors in the estimated source counts. To avoid this bias, the source count rates (and hence the hardness ratios and the flux) are estimated using the detector (MOS or PN) with no masked pixels in the vicinity of the source.

We convert counts to flux assuming a power-law spectrum with $\Gamma = 1.7$ and the appropriate Galactic absorption for each field listed in Table 1 (Dickey & Lockman 1990). The mean count-rate to flux conversion (or Energy Conversion Factor, ECF) for the mosaic of all three detectors is estimated by weighting the ECFs of individual detectors by the respective exposure time. For the encircled energy correction, accounting for the energy fraction outside the aperture within which source counts are accumulated, we adopt the calibration given by the XMM-Newton Calibration Documentation $^*$.  

3 THE SAMPLE

The SDSS optical photometric catalogue is used to identify optical counterparts to the X-ray sources by estimating the probability, $P$, that a given candidate is a chance coincidence (Downes et al. 1986). The probability depends on both the separation of the optical counterpart from the X-ray centroid and the surface density of the optical sources at the given magnitude (see Georgakakis et al. 2004 for details). For our identifications we adopt a probability threshold $P < 0.015$ and a maximum search radius of 7 arcsec.

We are further selecting sources which (i) are associated with galaxies i.e. they are optically extended sources according to the SDSS star-galaxy classification and (ii) have optical SDSS spectra available. A total of 33 sources fulfill the above criteria of which 14 have ‘early-type’ spectra showing absorption lines only and lacking emission lines. Finally, we exclude two sources which have low X-ray to optical flux ratio, log $f_X/f_{opt} < -2$ and therefore are most probably associated with ‘normal’ galaxies i.e. their X-ray emission comes from binaries and diffuse hot gas (see Hornschemeier et al. 2003). Both these sources are detected at the vicinity of the cluster Abell2670, having a redshift of $z=0.07$, and are most likely associated with the above cluster. Their X-ray coordinates (J2000) are $\alpha = 23^h 53^m 40.5^s$, $\delta =$  

$^*$ http://xmm.vilspa.esa.es/external/xmmwst/calib/documentation.shtml#XRT

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Table 1. The archival XMM-Newton pointings used in this study.

| RA (J2000) | Dec (J2000) | FILTER | N\textsubscript{H} (10\textsuperscript{20} cm\textsuperscript{-2}) | PN exp. time (sec) | MOS1 exp. time (sec) | Field name |
|------------|-------------|--------|-----------------|-------------------|---------------------|-------------|
| 23 54 09   | -10 24 00   | MEDIUM | 2.91            | 13 600            | 19 100              | ABELL 2670 |
| 23 37 40   | +00 16 33   | THIN   | 3.82            | 8 200             | 13 300              | RXCJ 2337.6+0016 |
| 17 01 23   | +64 14 08   | MEDIUM | 2.65            | 2 300             | 3 900               | RXJ 1701.3  |
| 15 43 59   | +53 59 04   | THIN   | 1.27            | 14 200            | 19 200              | SBS 1542+541 |
| 13 49 15   | +60 11 26   | THIN   | 1.80            | 14 100            | 18 100              | NGC 5322   |
| 13 04 12   | +67 30 25   | THIN   | 1.80            | 14 600            | 17 100              | ABELL 1674 |
| 12 45 09   | +00 27 38   | MEDIUM | 1.73            | 46 300            | 55 500              | NGC 4666   |
| 12 31 32   | +64 14 21   | THIN   | 1.98            | 26 100            | 30 100              | MS 1229.2+6430 |
| 09 35 51   | +61 21 11   | THIN   | 2.70            | 20 400            | 33 900              | UGC 5051   |
| 09 34 02   | +55 14 20   | THIN   | 1.98            | 23 500            | 28 500              | IZW 18     |
| 09 17 53   | +51 43 38   | MEDIUM | 1.44            | 15 900            | 13 600              | ABELL 773  |
| 08 31 41   | +52 45 18   | MEDIUM | 3.83            | 66 800            | 73 300              | APM 08279+5255 |
| 03 57 22   | +01 10 56   | THIN   | 13.20           | 19 100            | 21 400              | HAWAII 167 |
| 03 38 29   | +00 21 56   | THIN   | 8.15            | 8 900             | 6 700               | SDSS 033829.31+00215 |
| 03 02 39   | +00 07 40   | THIN   | 7.16            | 38 100            | 46 900              | CFRS 3H    |
| 02 56 33   | +00 06 12   | THIN   | 6.50            | 11 600            | –                   | RX J0256.5+0006 |
| 02 41 05   | -08 15 21   | MEDIUM | 3.07            | 12 300            | 15 600              | NGC 1052   |
| 01 59 50   | +00 23 41   | MEDIUM | 2.65            | 3 800             | –                   | MRK 1011   |
| 01 52 42   | +01 00 43   | MEDIUM | 2.80            | 5 800             | 17 200              | ABELL 267 |
| 00 43 20   | -00 51 15   | MEDIUM | 2.33            | 15 700            | –                   | UM 269     |

Figure 1. The optical spectra of the six sources that are likely to be associated with AGN.
−10^4. 24^m. 20^s. and \( \alpha = 23^h.54^m.5.7^s, \delta = -10^d.18^m.31^s. \) Their luminosities in the 0.5-8 keV band are \( 3 \times 10^{41} \) and \( 10^{42} \) erg s\(^{-1}\) respectively. The optical and X-ray properties of the remaining 12 sources are presented in Table 2. The optical spectra of the six sources which are likely to be associated with AGN (see the discussion section) are shown in Fig. 1. Clearly our selection criteria do not provide a complete sample of XBONGs that can be used for statistical studies (e.g. surface density of XBONGs). Nevertheless, our galaxies span a range of X-ray–to–optical flux ratios (see studies (e.g. surface density of XBONGs).)

Figure 2. The X-ray to optical flux diagram for the 12 XBONGs in our sample compared to the 10 XBONGs from Comastri et al. (2003). The solid lines indicate constant X-ray–to–optical flux ratios of log \( f_X/f_{opt} = \pm 1 \) and delineate the region of the parameter space occupied by powerful AGNs.

4 THE X-RAY SPECTRA

4.1 Hardness Ratios

In Fig. 3 we plot the hardness ratio as a function of the \( g - r \) colour. The hardness ratio, HR, is defined as

\[
HR = \frac{\text{RATE}(0520) - \text{RATE}(2080)}{\text{RATE}(0520) + \text{RATE}(2080)},
\]

where \( \text{RATE}(0520) \) and \( \text{RATE}(2080) \) are the count rates in the 0.5-2 and 2-8 keV spectral bands respectively. For one source (4), we have less than 5 counts in the hard band and thus we can estimate only a 3\( \sigma \) upper limit on the hardness ratio. The hardness ratios are estimated using the PN data except for sources that lie close to PN CCD gaps or hot pixels where we use MOS data (see section 2.2). These sources are marked in Table 2.

For comparison in Fig. 3 we also plot the line which corresponds to a power-law spectrum with photon index \( \Gamma = 1.9 \) and an absorbing column of \( N_H = 10^{20} \) cm\(^{-2}\) for the MOS detector. Note however, that as the MOS has a lower effective area at low energies, compared to the PN, the same hardness ratio corresponds to slightly different \( N_H \) values. The vast majority of sources present soft spectra, with values of the hardness ratio clustering around −0.5. All sources present red colours (\( g - r > 0.5 \)) typical of early-type systems.

4.2 Spectral Fits

Next, we attempt to constrain the spectral properties of the subsample of the 9 sources in Table 2 (sources #1, 2, 3, 6, 7, 8, 10, 11, 12) that have sufficient counts to perform X-ray spectral analysis. For the remaining sources ( #4, 5, 9) poor photon statistics do not allow spectral fittings to be performed. The source spectra are extracted using a radius of 18 arcsec. In most cases, the background spectrum is estimated from nearby image regions free from sources. In the case of the sources #2, 11 and 12 which are embedded in strong cluster emission, the background was taken from adjacent regions in the cluster. Response matrices and auxiliary files are generated using the SAS tasks rmfgen and arfgen respectively. We use the XSPEC v11.2 software to perform the spectral fits. The quoted errors correspond to

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the 90 per cent confidence level. The spectral fits are performed in the 0.3-8 keV band where the instruments calibration are well known. In the case of the sources #1, 6, 10, 11 and 12 we have a sufficient number of counts (more than 15 counts per bin) to perform $\chi^2$ statistics. In the other cases (#2, 3, 7, 6) where much fewer counts are observed, we use the C-statistic instead (Cash 1979) which does not require for the binning of the data. The disadvantage is that the C-statistic does not allow for the derivation of the goodness-of-fit probability unlike the $\chi^2$ statistic.

We fit two models to the spectra: a Raymond-Smith model which provides a good representation of the hot gas emission in early-type normal galaxies, and a power-law model which is characteristic of AGN spectra. The spectral fit results are given in Table 3. Examples of the X-ray spectra of the two X-ray brighter sources in the sample (not associated with extended X-ray emission) are shown in Figure 4. The values with no errors denote that the parameter is tied during the fitting. The column density is fixed in most cases to the Galactic value (Dickey & Lockman 1990). In the case of the Raymond-Smith model, the abundance is fixed to $Z = 0.3$. Comparison of the resulting $\chi^2$ values of the Raymond-Smith and the power-law models (Mushotzky 1982) in the case of sources #1, 11 and 12 demonstrates that the Raymond-Smith spectrum provides a significantly better fit compared to the power-law spectrum. The best fit temperatures are $\sim 1$ keV typical for early-type galaxies or groups (Matsumoto et al. 1997). This strongly suggests that the X-ray emission in these objects is associated with hot gas emission. Sources #11 and 12 are not extended and thus are likely associated with gas heated by the gravitational potential of a galaxy. Sources #1 as well as 6, 8, 10 are extended and thus most likely associated with groups (#1, 6, 8) or clusters of galaxies (#10).

The best fit temperature kT $\sim 1 - 3$ keV and luminosities $L_X(0.5 - 8$ keV $) \sim 10^{42} - 10^{44}$ erg s$^{-1}$ are consistent with the above interpretation. The spectral fits for sources #2, 3 and 7 are good for both the Raymond-Smith and the power-law models. Therefore, these could be in principle associated with either normal galaxies or unobscured AGN. However, the best fit temperatures are higher (2-5 keV) than those of normal galaxies favoring, together with high X-ray luminosities, the AGN case.

### Table 2. Optical and X-ray properties of the 12 XBONGs identified in this study

| # | RA (J2000) | Dec (J2000) | $z$ | Offset (arcsec) | $r$ | $f_X^2$ | HR | $\log f_X/f_{opt}$ | $L_X^2$ | $M_r$ | Class | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 01 53 15.2 | +01 02 20 | 0.060 | 0.3 | 14.73 | 21.5 | $-0.93 \pm 0.06^2$ | -1.39 | 2.2 | -22.58 | Group | ABELL267 |
| 2 | 02 56 30.8 | +00 06 02 | 0.373 | 1.3 | 18.28 | 4.1 | $-0.41 \pm 0.07^2$ | -0.21 | 21.5 | -23.40 | AGN | RXJ0256.5 |
| 3 | 03 01 53.9 | +00 15 37 | 0.383 | 3.5 | 18.95 | 1.1 | $-0.15 \pm 0.27^1$ | -1.00 | 6.0 | -22.80 | AGN | CFRR3H |
| 4 | 03 38 10.0 | +00 16 10 | 0.198 | 1.6 | 16.77 | 1.8 | $< -0.34^1$ | -1.65 | 2.3 | -23.35 | AGN/Gal? | SDSS033832 |
| 5 | 09 36 19.4 | +01 27 21 | 0.131 | 2.3 | 16.55 | 0.95 | $-0.76 \pm 1.0^2$ | -2.00 | 0.52 | -22.62 | AGN/Gal? | UGC5051 |
| 6 | 12 44 54.5 | -00 26 39 | 0.231 | 0.8 | 16.91 | 0.84 | $-0.67 \pm 0.20^2$ | -1.93 | 1.5 | -23.60 | Group | NGC4508 |
| 7 | 13 03 28.8 | +07 26 41 | 0.430 | 2.5 | 19.14 | 2.4 | $-0.83 \pm 0.19^1$ | -0.59 | 17.3 | -22.89 | AGN | ABELL1694 |
| 8 | 13 02 40.3 | +07 28 42 | 0.106 | 1.1 | 15.53 | 5.3 | $-0.59 \pm 0.13^1$ | -1.67 | 1.9 | -23.16 | Group | ABELL1674 |
| 9 | 13 12 51.0 | +07 25 17 | 0.109 | 5.0 | 16.57 | 1.3 | $-0.56 \pm 1.0^1$ | -1.87 | 0.46 | -22.13 | AGN/Gal? | ABELL1674 |
| 10 | 17 01 23.8 | +64 14 13 | 0.452 | 1.8 | 19.16 | 19.3 | $-0.48 \pm 0.12^2$ | 0.34 | 159.7 | -23.02 | Group | RXJ1701.3 |
| 11 | 23 54 07.2 | -10 25 15 | 0.071 | 3.0 | 16.47 | 36.9 | $-0.69 \pm 0.04^2$ | -0.46 | 5.2 | -21.23 | Gal | ABELL2670 |
| 12 | 23 54 13.9 | -10 25 09 | 0.078 | 2.8 | 14.14 | 40.1 | $-0.52 \pm 0.04^2$ | -1.35 | 6.9 | -23.77 | Gal | ABELL2679 |

1 PN, 2 MOS, 3 in units $10^{-14}$ erg cm$^{-2}$ s$^{-1}$ (0.5-8 keV), 4 in units $10^{42}$ erg s$^{-1}$ (0.5-8 keV)$^5$ Classification based on X-ray properties

5 DISCUSSION

In this paper we explore the nature of the class of X-ray Bright Optically Inactive galaxies identified in public XMM-Newton fields that overlap with the SDSS. Our sample is selected in the 0.5-8 keV spectral band and comprises a total of 12 systems with $\log f_X/f_{opt} > -2$. These galaxies represent only a small fraction (1 per cent) of the full 0.5-8 keV selected catalogue totaling 1286 detections. One should bear in mind however, that our XBONGs do not constitute a complete sample as we selected only the optically brighter sources with available SDSS spectra.

A total of 8 sources are indeed, brighter than $\tau <$
This may suggest that our sample may preferentially probe served as part of the SDSS Luminous Red Galaxy sample. The region probed by our sources (10< r < 120 kpc) with luminosit-ies ∼ 10^{42} – 10^{44} erg s^{-1} suggesting diffuse hot gas from a cluster or group of galaxies. For the remaining sources the X-ray spectral properties provide constraints on their nature. In the case of sources #11, 12 (associated with the cluster Abell 2670) we find that a Raymond-Smith model provides a much better fit to the data compared to a power-law spectral energy distribution. The derived temperatures are ∼ 1 keV, as expected for the hot gas emission encountered in the weak gravitational potentials of early-type galaxies. The X-ray luminosities are high 5 – 7 × 10^{43} erg s^{-1} for thermal emission. However, such high levels of X-ray emission can be encountered in massive ellipticals especially those residing in clusters (eg. Paolillo et al. 2003; O’Sullivan, Ponman & Collins 2003). This is demonstrated in Figure 6 plotting the L_X – L_B for the XBONGs in our sample in comparison

Figure 5. The luminosity - redshift diagram for the XBONGs in our sample compared to those from Comastri et al. (2003).

Figure 6. The L_X – L_B relation for our galaxies (large symbols) in comparison with the early-type galaxy sample presented by O’Sullivan, Forbes & Ponman (2001). The small open circles and triangles represent detections and upper limits in the O’Sullivan et al. (2001) sample. The continuous line is the best fit to the O’Sullivan et al. (2001) data excluding the AGNs, Bright Cluster Galaxies and dwarfs. The dashed lines are the 1σ envelopes around the best fit.

Table 3. Spectral fits to the 9 brighter sources

| Object   | Raymond-Smith | Power-Law |
|----------|---------------|-----------|
|          | N_H^2 | kT      | χ^2  | N_H^2 | Γ    | χ^2 |
| 1        | 9^{+13}_{-5} | 0.91^{+0.05}_{-0.03} | 97.2/92 | 3 | 2.2^{+0.1}_{-0.1} | 400.9/94 |
| 2        | 7     | 5.3^{+2.3}_{-1.7} | - | 7 | 2.01^{+0.20}_{-0.19} | - |
| 3        | 7     | 6.8^{+2.06}_{-0.9} | - | 7 | 1.70^{+0.05}_{-0.04} | - |
| 6        | 1.7   | 1.62^{+0.42}_{-0.32} | 113.2/107 | 1.7 | 2.29^{+0.18}_{-0.17} | 120.9/107 |
| 7        | 2     | 2.18^{+0.62}_{-0.53} | - | 2 | 2.20^{+0.30}_{-0.27} | - |
| 8        | 2     | 2.20^{+0.60}_{-0.59} | - | 2 | 2.10^{+0.22}_{-0.21} | - |
| 10       | 3     | 4.83^{+2.03}_{-0.04} | 43.6/63 | 3 | 1.77^{+0.14}_{-0.13} | 42.8/63 |
| 11       | 3     | 1.10^{+0.94}_{-0.71} | 553/594 | 3 | 2.22^{+0.09}_{-0.08} | 716/594 |
| 12       | 3     | 1.34^{+0.24}_{-0.23} | 451/662 | 3 | 2.06^{+0.21}_{-0.20} | 468/662 |

1 Intrinsic rest-frame column density in units of 10^{20} cm^{-2}
with the best fit relation for early type galaxies (excluding AGNs, dwarfs and Bright Clusters Galaxies; O'Sullivan et al. 2001). Source #11 ($L_B = 1.4 \times 10^{42} L_{B\odot}$) lies well above the galaxy $L_X - L_B$ relation, indicating the presence of extended X-ray emission (O'Sullivan et al. 2003). Source #12 with $L_B \approx 10^{41} L_{B\odot}$ lies marginally above the 1σ envelope in Figure 6. Three additional sources (#4, 5, 9) may be associated with normal galaxies i.e. the X-ray emission may come from X-ray binaries and hot gas rather than a supermassive black hole. In the case of these sources the poor photon statistics do not allow us to derive spectral constraints from the X-ray spectral fitting. However, the hardness ratios of these objects suggest soft spectra. The X-ray luminosities of these objects are relatively low $< 2 \times 10^{32}$ erg s$^{-1}$, consistent with those of normal galaxies or low luminosity AGN (e.g. LINERs).

Sources #2, 3, 7 present soft X-ray spectra consistent with either a power-law or a Raymond-Smith spectrum. The power-law photon index has a value of $\Gamma \approx 2$ typical of an unobscured AGN spectrum. The best-fit temperatures in the case of a Raymond-Smith model are relatively high (2-5 keV) more typical of galaxy clusters than normal galaxies. The lack of extended X-ray emission lends no support to the weak ionizing continuum case. Alternatively, dilution of the nuclear light (Ward et al. 1988), lending no support to the weak ionizing case. In this case the absence of optical emission lines is consistent with the central galaxy of the cluster and these often present enhanced X-ray emission (O'Sullivan et al. 2003). Source #12 with $L_B \approx 10^{41} L_{B\odot}$ lies marginally above the 1σ envelope in Figure 6. Three additional sources (#4, 5, 9) may be associated with normal galaxies i.e. the X-ray emission may come from X-ray binaries and hot gas rather than a supermassive black hole. In the case of these sources the poor photon statistics do not allow us to derive spectral constraints from the X-ray spectral fitting. However, the hardness ratios of these objects suggest soft spectra. The X-ray luminosities of these objects are relatively low $< 2 \times 10^{32}$ erg s$^{-1}$, consistent with those of normal galaxies or low luminosity AGN (e.g. LINERs).

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that a population of hidden AGN is hosted in apparently normal galaxies is intriguing. This could partially explain the scarcity of obscured AGN in the deep Chandra surveys. However, in our sample, we find no significant evidence for flat X-ray spectra or equivalently large absorbing columns. We note again however, that our sample may be biased against such heavily obscured sources, as it is selected in the total 0.5-8 keV band. Indeed, as the effective area of XMM-Newton is high at soft energies, the total energy band contains a large number of soft sources and hence, the fraction of absorbed XBONG may be low. Our sample is further biased against high flux objects as it is selected to contain optically bright sources with spectroscopic information available in SDSS. We nevertheless believe that the latter does not introduce any bias against obscured XBONG. At relatively low redshifts \( z \approx 0.4 \) a large absorbing column will reduce the X-ray emission relative to the optical and results in low flux values; for example the source 031238.9-765134 (Comastri et al. 2002) has log flux \( f_{\text{opt}} \approx -1 \). Interestingly, the hard to soft band flux ratios of many XBONG in the sample of Comastri et al. (2003), especially those selected in the XMM-Newton fields, are consistent with soft X-ray spectra (see their Fig. 4).

6 CONCLUSIONS

We explore the X-ray properties of a sample of 12 X-ray bright optically inactive galaxies (XBONG). These are detected in 20 XMM-Newton fields in the total 0.5-8 keV band overlapping with the SDSS. We concentrate on those systems with available SDSS optical spectroscopic information and select sources which present only absorption lines in their optical spectra. We further select our objects to have high X-ray to optical flux ratios \( f_X/f_{\text{opt}} > -2 \) to reduce contamination by normal galaxies. The resulting sample comprises (i) extended X-ray sources most probably associated with galaxy clusters, (ii) normal galaxies and (iii) unobscured AGN. The unobscured AGN do not present emission lines probably because the optical light from the nucleus is diluted by a strong galaxy component (e.g. Moran et al. 2002; Severgnini et al. 2003, Georgantopoulos et al. 2003). Previous work (Comastri et al. 2002) has suggested that the lack of optical emission lines in XBONGs could be attributed to the fact that the central source suffers from large obscuration. We find no evidence in our sample for the presence of XBONGs which present significant X-ray absorption. As we imposed a cut-off in optical magnitude, our sample is not complete and therefore we cannot conclusively rule out the possibility that some XBONGs fainter that our magnitude limit present X-ray absorption. Nevertheless, our present work shows that the absence of optical emission lines in at least a fraction of XBONGs, can be explained from the dilution rather than absorption of the optical nuclear light.

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