IOP Conf. Series: Journal of Physics: Conf. Series **869** (2017) 012086 doi:10.1088/1742-6596/869/1/012086

Searching for Compton-thick AGNs with XMM-Newton observations

R Mostafa[1], M Guainazzi[2] and A Ibrahim[3,4]

[1] Fayoum University, Physics Department, Science Faculty, Fayoum, Egypt
[2] European Space Research and Technology Centre, Noordwijk, The Netherlands
[3] Zewail City of Science and Technology, Physics of Earth and Universe, and
[4]Cairo University, Faculty of Science, Physics Department, Giza, Egypt

E-mail: rma04@fayoum.edu.eg

Abstract. Most Active galactic nuclei (AGNs) are obscured by large column densities of cold and neutral gas. If the X-ray obscuring matter has a column density equal to or larger than the inverse of the Thomson cross-section ($N_H \geq \sigma_T \approx 1.5\times10^{24}$ cm^{-2}), then the source is identified as a Compton-thick AGN. One of the characteristics of Compton-thick AGN is the presence of Fe Kα emission line in their spectra with a large equivalent width. Using this criterion with XMM-Newton observations we identified Compton-thick AGNs by following a selection method, the FLEX algorithm, developed by Maccacaro *et al* [1] to search for X-ray line emitting objects (XLEOs). This technique detects the sources having significant excess of photons resulting from the iron emission line. Here we present the results from applying this method on the 28 highly absorbed AGNs recently detected by Corral *et al* [2]. Of these 28 AGN, 15 are candidate Compton-thick AGN. We applied the detection algorithm on a pilot sample of 40 XMM-Newton observations. Our results confirm the Compton-thick nature of 14 of Compton-thick AGN, based on the observed properties of the Fe Kα emission line. We use the characteristics of the observed lines to diagnose the AGNs and their environments.

1. Introduction

Compton-thick active galactic nuclei (AGNs) are obscured by large absorbed column density ($N_H \geq 1.5\times10^{24}$ cm^{-2}). According to the standard unification model, in Seyfert 2 galaxies the powerful engine is obscured by a molecular torus surrounding the accretion disc [3]. Detection of Compton-thick sources can be probed by the presence of a strong iron Kα line complex at 6.4-7 keV and Compton reflection component. At these high column densities, the iron line equivalent width (EW) reaches values of order 1 keV and in case of high inclination angles and small torus opening angles it increases for several keV. A smaller opening angle means the torus obscures a larger solid angle around the nucleus, and hence more Fe K-edge photons are captured and generate Kα photons. High inclination angle closer to the equatorial plane see larger EWs in the Kα line because the continuum is most severely attenuated along that direction. Large optical depth promotes Kα production by absorbing more hard X-rays: the continuum at Kα is suppressed, while photons well above the Fe K-edge are absorbed and trigger

IOP Conf. Series: Journal of Physics: Conf. Series **869** (2017) 012086 doi:10.1088/1742-6596/869/1/012086

fluorescence but for optical depth more than ≈ 4 the EW decreases because the optical depth from the points of Kα production to the surface is too large for the fluorescence photons to escape [4].

A recent selection technique to search for highly obscured AGNs was discussed by Corral *et al* [2]. They applied automated X-ray spectral fits implemented for the XMM-Newton spectral fit database and the selection of highly obscured candidates was based on the presence of either (a) flat rest-frame spectra from a simple power-law fit; (b) flat observed spectra from an absorbed power-law fit; (c) an absorption turnover, indicative of a high rest-frame column density; or (d) the presence of an Fe Kα line with a large equivalent width (EW >500 eV). More detailed manual spectral fits result in a detection of 28 heavily obscured with column density higher than 10^{23} cm^{-2}. A novel search method FLEX (Finder for Line Emitting X-ray sources) to search for X-ray line emitting objects (XLEOs) in XMM-Newton observations has been developed by Maccacaro *et al* [1]. They detected three sources, most likely highly absorbed AGNs ($N_H > 10^{24}$ cm^{-2}) in a test-run analysis of 13 XMM-Newton observations. The idea is based on the extension to the energy axis of the usual source detection techniques and a search for a significant excess is performed along the energy axis. Here, we apply this selection method technique on the 28 highly absorbed AGNs detected by [2] to test the reliability of this selection technique.

2. Data reduction and detection method

The sample is composed of 40 observations from XMM-Newton serendipitous source catalog (3XMM-DR4) corresponding to 28 sources, which were detected as heavily absorbed sources by Corral *et al* [2]. We reduced the EPIC-PN data using SAS v15.0.0. Data were first processed through the pipeline chains, and then filtered. Events with flag=0 and pattern between 0 and 4 were used. The selected energy range (2.3-6.4 keV) includes all sources with redshift interval 0-1.8. For each of the 41 observations, PN images are created in 23 energy bands in the energy range (2.1-6.7 keV), we increase one bin on each side, each band in 200 eV. For one source, 3XMM141546.2+112943, we extended the lower energy limit to be (1.7-6.4 keV) due to its high redshift (z = 2.56). Then we applied the detection meta-task edetect chain for all 23 energy bands. The three-dimensional detection cell has a box size 5×5 pixels and energy size 200 eV. We rejected the energy bands of sources with detection likelihood smaller than 11.5 (corresponding to probability greater than ~10^{-5}). We find 38 observations out of 41, corresponding to 27 sources, having excess source counts with a probability of being fluctuation of the estimated background level smaller than ~ 10^{-5}.

3. Spectral analysis and results

In order to distinguish Compton-thick from other AGN types that exhibit the iron emission line we have to differentiate the excess counts of iron line from the continuum counts in the energy bands where excess is detected with a probability of being a random noise fluctuation less than ~ 10^{-5}. To do this, we applied the following method. Only EPIC-PN data is used. For each observation, we extracted the source and background spectrum from a circular region with the same area. Source spectra were checked for pile-up. All spectra were binned to 1 counts bin^{-1} and Cash-statistics [5] was used for modeling the spectra in XSPEC v12.9.0. A simple model composed of absorbed power-law plus a Gaussian emission line whose energy is fixed to 6.4 keV rest-frame and width to 0.1 keV [zwabs*(pow+zgau) in XSPEC] were applied to the spectra in the energy range 2.0 - 10.0 keV. We determined the flux from both the best-fit model and the model with line normalization set to zero in each detected energy band for the 38 observations. We then estimated the continuum counts from the ratio of both fluxes and the source counts from edetect_chain.

The results are listed in table 1. For each source, the energy range with the most excess from the Kα iron line and the fraction of this excess with respect to the source counts are shown in table 1. Three sources are discarded since we did not detect any excess from the line. In type2 AGN the torus

IOP Conf. Series: Journal of Physics: Conf. Series **869** (2017) 012086 doi:10.1088/1742-6596/869/1/012086

Table 1. Detected sources

Source Name	Energy band (keV)	Source counts	Line (%)	EW (keV)	Classification	A. Corral Classification
3XMMJ080741.0+390015[(a)]	6.1-6.3	10.5	77.7	$0.927^{+0.76}_{-0.63}$	CT	CT
3XMMJ215649.5-074531[(b)]	5.9-6.1	11.2	61.6	$0.316^{+0.84}_{-0.32}$	CT candidate	CT
3XMMJ093551.5+612111[(b)]	6.1-6.3	33.5	67.4	$0.907^{+0.63}_{-0.47}$	CT	CT
3XMMJ093952.7+355358[(b)]	5.5-5.7	44.2	62.8	$0.862^{+0.73}_{-0.86}$	CT	CT
3XMMJ103408.5+600152[(b)]	5.9-6.1	17.7	90.8	$1.647^{0.56}_{-1.65}$	CT	CT
3XMMJ113549.0+565708[(a)]	6.1-6.3	8.15	55.8	$0.119^{+1.06}_{-0.12}$	CT candidate	CT
3XMMJ115704.8+524903[(a)]	6.1-6.3	29	85.6	$1.445^{+2.19}_{-0.83}$	CT	CT
3XMMJ121839.4+470626[(b)]	5.7-5.9	11	74.3	$0.349^{+0.92}_{-0.35}$	CT candidate	CT
3XMMJ122546.7+123943						
OBID 0110930301[(a)]	6.3-6.5	193.5	61.3	$0.538^{+0.15}_{-0.12}$	-	CT
OBID 0110930701[(b)]	6.3-6.5	748	51.4	$0.229^{+0.08}_{-0.06}$	-	-
OBID 0675140101[(a)]	6.3-6.5	3234	25.3	0.083 ± 0.01	-	-
3XMMJ131104.6+272806[(b)]	5.1-5.3	9.26	90.5	$1.937^{+1.95}_{-1.35}$	CT	CT
3XMMJ140700.3+282714[(b)]	5.9-6.1	24.7	75.8	$1.100^{+0.69}_{-0.58}$	CT	CT
3XMMJ141546.2+112943						
OBID 0112250301[(b)]	1.7-1.9	15	21	$0.018^{+1.76}_{-0.02}$	CT candidate	CT
OBID 0112251301[(b)]	1.7-1.9	21.5	54.4	0.239 ± 0.25	-	CT
3XMMJ150754.3+010817[(a)]	5.9-6.1	17.4	81.4	$1.095^{+1.94}_{-0.81}$	CT	CT
3XMMJ153457.2+233011						
OBID 0101640901[(b)]	6.3-6.5	6	54.8	$0.135^{+5.99}_{-0.13}$	CT candidate	CT
OBID 0205510401[(b)]	6.3-6.5	13.1	77.1	$3.662^{+7.60}_{-3.66}$	CT	CT
3XMMJ082443.2+295923[(a)]	6.1-6.3	109.6	61.8	$0.272^{+0.14}_{-0.11}$	-	-
3XMMJ083139.0+524205						
OBID 0092800201[(a)]	5.9-6.1	42	51	$0.436^{+0.49}_{-0.26}$	-	-
OBID 0502220201[(a)]	5.9-6.1	21.1	52	$0.470^{+0.52}_{-0.41}$	-	-
OBID 0502220301[(a)]	5.9-6.1	12.9	38	$0.118^{+0.28}_{-0.12}$	-	-
3XMMJ084002.3+294902[(b)]	5.9-6.1	89.5	65.5	$0.405^{+0.31}_{-0.27}$	-	-
3XMMJ095906.6+130134[(b)]	6.1-6.3	61.3	36.6	$0.144^{+0.29}_{-0.14}$	-	-
3XMMJ104930.9+225752[(b)]	6.1-6.3	65.4	40	$0.127^{+0.17}_{-0.13}$	-	-
3XMMJ113240.2+525701						
OBID 0200431301[(b)]	6.1-6.3	28.8	50.9	$0.425^{+0.57}_{-0.42}$	-	-
OBID 0200430501[(b)]	6.1-6.3	24.4	59	$0.203^{+0.22}_{-0.20}$	-	-
3XMMJ120429.6+201858[(b)]	6.1-6.3	15.5	62.2	$0.463^{+0.64}_{-0.46}$	CT candidate	-
3XMMJ080535.0+240950[(a)]	5.9-6.1	13	63.3	$0.381^{+0.57}_{-0.38}$	-	-
3XMMJ123843.4+092736[(b)]	5.9-6.1	81.3	39.2	$0.049^{+0.10}_{-0.05}$	-	-
3XMMJ132348.4+431804[(a)]	6.1-6.3	89.1	62.2	$0.382^{+0.26}_{-0.17}$	-	-

[a] zwabs*(pow+zgau)
[b] zwabs*(pow+zgau)+pow

intercepted along the line of sight and the primary radiation is absorbed up to energies that depend on the column density of the obscuring material. A fraction of this direct radiation is reprocessed producing Fe Kα emission lines. For high column densities (Compton thick) almost the primary radiation is absorbed, enhancing the production of the iron line. So we anticipate that sources with a continuum spectrum dominated by high excess counts from the emission line to be a Compton-thick source. Therefore, sources which are highly dominated by the iron line by a fraction larger than 75% are most likely to be Compton-thick AGNs. The critical parameter here is the equivalent width of the kα iron line with respect to the underlying continuum. Therefore, we fitted the spectra in the energy range 4.0-8.0

keV (1.5-8.0 keV for high redshift source) with the two-component model: absorbed power-law and Gaussian line using C-stat in XSPEC. Another component: the unabsorbed power-law, which represents the scattered contribution, is added if it is significantly required (indicated by the goodness of fit in XSPEC). The two power-law indices are tied to have the same value. A prominent Fe Kα line with large EW > 1 keV is a common feature of Compton-thick AGN [4]. So we classified the 6 sources with EW > 1 keV as Compton-thick sources. If we take into consideration, the 90% confidence level values of EW another 5 sources are classified as Compton-thick candidate. We finally considered an additional three sources as CT sources with an EW > 550 eV according to the prediction that EW reaches a maximum value of 550 eV [6].

4. Discussion

We have applied a modified method presented by Maccacaro *et al* [1] to search for Compton-thick AGN based on the detection of the excess from Fe k-α emission line. This is followed by spectral fitting to estimate the equivalent width of Fe Kα emission line with respect to the continuum. From 40 observations, we detected the sources in 32 observations, corresponding to 24 individual sources. We classified the 24 sources as 9 CT if EW is larger than 550 eV and 5 CT candidates if EW is larger than 1 keV within the 90% confidence level. Out of 14 CT and CT candidates, 13 are consistent with being CT AGN as detected by Corral [2]. Only one CT candidate in our sample (3XMMJ120429.6+201858) was not classified as CT AGN by Corral [2] whereas we did not detect two of their CT AGNs (3XMMJ091804.2+514113 and 3XMMJ122546.7+123943). For 3XMMJ091804.2+514113 we did not find any line excess, probably because of its very low counts. Although we detected a line excess in 3XMMJ122546.7+123943 the EW do not obey our CT classification. In addition, those two sources disagree with a previous classification as reported by Corral *et al* [2].

Moreover, we find that all 7 detected sources with line fraction > 75% are classified as CT sources. This is consistent with in the Compton-thick AGN where the intrinsic continuum is strongly reprocessed. For the other 17 remaining sources, we could not classify them through this prediction and the estimation of their equivalent width is needed. Finally, our results from this detection technique agree with that reported by Corral *et al* [2].

References

[1] Maccacaro T, Braito V, Della Ceca R, Severgnini P and Caccianiga A 2004 *ApJ* **617** L33
[2] Corral A *et al* 2014 *A&A* **569** A71
[3] Comastri A 2004 *in Astrophysics and Space Science Library* vol 308, ed Barger A J chapter 8 pp 245
[4] Levenson N A, Krolik J H, Zycki P T, Heckman T M, Weaver K A, Awaki H and Terashima Y 2002 *ApJ* **573** L81
[5] Cash W 1979 *ApJ* **228** 939
[6] Zycki P T and Czerny B 1994 *MNRAS* **266** 653