X-ray absorption variability in NGC 4507

Andrea Marinucci, Guido Risaliti, Junfeng Wang, Stefano Bianchi, Martin Elvis, Giorgio Matt, Emanuele Nardini and Valentina Braito

1 Dipartimento di Fisica, Università degli Studi Roma Tre, via della Vasca Navale 84, I-00146 Roma, Italy
2 Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
3 INAF – Osservatorio Astrofisico di Arcetri, L.go E. Fermi 5, Firenze, Italy
4 INAF – Osservatorio Astronomico di Brera, Via E. Bianchi 46, I-23807 Merate, Italy

ABSTRACT

We present a complete spectral analysis of an XMM–Newton and Chandra campaign of the obscured AGN in NGC 4507, consisting of six observations spanning a period of six months, ranging from 2010 June to December. We detect strong absorption variability on time-scales between 1.5 and 4 months, suggesting that the obscuring material consists of gas clouds at parsec-scale distance. The lack of significant variability on shorter time-scales suggests that this event is not due to absorption by broad-line region (BLR) clouds, which was instead found in other studies of similar sources. This shows that a single, universal structure of the absorber (either BLR clouds, or the parsec-scale torus) is not enough to reproduce the observed complexity of the X-ray absorption features of this AGN.

Key words: Galaxies: active – Galaxies: Seyfert.

1 INTRODUCTION

The standard unification model for active galactic nuclei (AGN) assumes the same internal structure for Seyfert 2 and Seyfert 1 galaxies (Antonucci 1993), with all the type 1/2 observational differences ascribed to an axisymmetric absorber/reflector, located between the broad-line region (BLR) and the narrow-line region (NLR), in order to obscure the former, but not the latter. An early developed, natural geometrical and physical scenario is that of a homogeneous torus on a parsec scale (Krolik & Begelman 1988); however, recent studies on X-ray absorbing column density changes performed with Chandra, XMM–Newton and Suzaku satellites ruled out a universal geometrical structure of the circumnuclear absorber. Absorption variability is common (almost ubiquitous) when we compare observations months to years apart (Risaliti, Elvis & Nicastro 2002), and, most notably, has been found on time-scales of hours to days in several sources, such as NGC 1365 (Risaliti et al. 2005, 2007, 2009), NGC 4388 (Elvis et al. 2004), NGC 4151 (Puccetti et al. 2007) and NGC 7582 (Bianchi et al. 2009).

NGC 4507 is a nearby (z = 0.0118) barred spiral galaxy and one of the X-ray brightest Compton-thin Seyfert 2s, despite the heavy obscuration (N_H \sim 4.9 \times 10^{23} \text{ cm}^{-2}). It was first observed in the X-rays by Einstein (L_X = 2.8 \times 10^{41} \text{ erg s}^{-1}; Kriss, Canizares 

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cameras, the PN (Strüder et al. 2001) and the two MOS (Turner et al. 2001), operated in large window and medium filter mode. The extraction radii and the optimal time cuts for flaring particle background were computed with SAS 11 (Gabriel et al. 2004) via an iterative process which leads to a maximization of the signal-to-noise ratio, similarly to that described in Piconcelli et al. (2004). After this process, the net exposure times for the five different observations were 16, 13, 13, 17 and 17 ks for the PN, respectively. The resulting optimal extraction radii are 40 arcsec for the first three observations, 30 arcsec for the fourth one, 26 arcsec for the last one. The background spectra were extracted from source-free circular regions with a radius of about 50 arcsec for all the five observations. We also re-extracted the data from a previous XMM–Newton observation (obsid 0006220201), with a net exposure of about 36 ks, adopting an extraction radius of 40 arcsec for the source and 42 arcsec for the background. The analysis of the last set of data is discussed in Matt et al. (2004).

Chandra observed the source on 2010 December 2 for 44 ks, with the Advanced CCD Imaging Spectrometer (ACIS; Garmire et al. 2003). Data were reduced with the Chandra Interactive Analysis of Observations (CIAO; Fruscione et al. 2006) 4.4 and the Chandra Calibration Data Base (CALDB) 4.4.6 data base, adopting standard procedures, using a 2 and 10 arcsec extraction radii for the source and background, respectively.

Spectra were binned in order to oversample the instrumental resolution by at least a factor of 3 and to have no less than 30 counts in each background-subtracted spectral channel. This allows the applicability of the $\chi^2$ statistics.

3 DATA ANALYSIS

The adopted cosmological parameters are $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.73$ and $\Omega_{\Lambda} = 0.27$, i.e. the default ones in XSPEC 12.7.0 (Arnaud 1996). Errors correspond to the 90 per cent confidence level for one interesting parameter ($\Delta \chi^2 = 2.7$), if not otherwise stated.

3.1 EPIC PN/MOS spectral analysis

The soft 0.5–3.0 keV spectrum presents a strong ‘soft excess’, which appears dominated by emission lines from an highly ionized gas, as observed in most X-ray obscured AGN (Turner et al. 1997; Guainazzi & Bianchi 2007). Emission lines from H-like and He-like C, N, O and Ne, as well as from the Fe L-shell, have been detected and reported in previous observations (Matt et al. 2004).

Following Matt et al. (2004), the baseline model we used to fit the 0.5–10 keV spectra can be roughly expressed by the following general formula:

$$F(E) = e^{-\sigma(E)N_H} \left[ P h_{\alpha} + C + e^{-\sigma(E)N_H} B E^{-\Gamma} \right.$$

$$\left. + R(\Gamma) + \sum_i G_i(E) \right], \quad (1)$$

where $\sigma(E)$ is the photoelectric cross-section (abundances as in Anders & Grevesse 1989), $N_H$ is the Galactic absorbing column density along the line of sight to the source (Dickey & Lockman 1990); $P h_{\alpha}$ is the emission from a photoionized gas reproduced with self-consistent CLOUDY models as described in Bianchi et al. (2010) and Marinucci et al. (2011) while $C$ is the emission from a collisionally ionized diffuse gas (APEC model; Smith et al. 2001); $N_H$ is the neutral absorbing column density at the redshift of the source; $B$ is the normalization of the primary power law with slope $\Gamma$; $R(\Gamma)$ is the Compton scattering from the inner layer of the circumnuclear torus, modelled in XSPEC with PEXRAV (Magdziarz & Zdziarski 1995); $G_i(E)$ are Gaussian profiles, corresponding to required emission lines of high-Z elements such as the Fe Kα at 6.4 keV, Fe Kβ at 7.058 keV, Fe XXVI at 6.966 keV and the forbidden line of the Fe XXV Kα triplet (see Table 1).

A further Gaussian emission line has been used to reproduce the Compton shoulder (CS) redwards of the iron line core, as expected on theoretical grounds, with energy fixed at 6.3 keV and $\sigma = 40$ eV (Matt 2002).

The reflected, Compton scattered emission has been modelled using the PEXRAV model with $\Gamma = 1.8$ and normalization fixed to the values measured with the broad-band Suzaku observation (B12). The previous model has been used to fit, in first place, the five separate EPIC PN/MOS observations. The five spectral fits from our campaign in Summer 2010 (labelled as Obs. 1–5 in Table 1) have good $\chi^2/{\text{dof}}$ and do not present any strong evidence of variations in either the absorbing column density or $\Gamma$ (Fig. 1). The Obs. 2 data set presents strong residuals mainly between 1.5 and 3.0 keV, more evident in the EPIC-MOS spectra. Since they are located in very narrow bins at $\sim 2.8$, $\sim 1.6$ and $\sim 1.9$ keV and they cannot be ascribed to known spectral features, we believe that they are due to background/calibration issues.

Two different photoionized phases and a collisional one are needed to model the 0.5–3.0 keV spectra of NGC 4507. Table 1 clearly shows that the soft X-ray emitting gas has not varied during the monitoring. This suggests that the intervening absorbing material, responsible for the column density variation between 2010 June and December, might be much closer to the X-ray source than the circumnuclear matter responsible for the soft emission. As already discussed in Bianchi, Guainazzi & Chiaferri (2006) and Bianchi & Guainazzi (2007), this gas is likely coincident with the NLR. Further studies on the photoionization mechanisms and extended emission in NGC 4507 will be discussed in detail in the future (Wang et al., in preparation).

We then analysed the 10 spectra (5 EPIC PN and 5 MOS1+2, labelled as Set 1 in Table 1) simultaneously, using the model described above and linking all the parameters, except for the flux normalizations. The baseline model reproduces the five sets of data

![Figure 1. XMM–Newton EPIC PN 0.5–10 keV best fit and residuals for the five observations of the campaign described in this work.](https://academic.oup.com/mnras/article-abstract/429/3/2581/1010491)
and some residuals are present around 1.8 keV. Indeed, the addition of a line at 1.77 ± 0.03 keV is required (Δχ² = 44, with a significance greater than 99.99 per cent, according to F-test); it can be identified as Si Kα, with a corresponding flux of 2.0 ± 0.4 × 10⁻⁶ ph cm⁻² s⁻¹. The primary power law (Γ = 1.8±0.2) is absorbed by a column density of 9.0 ± 0.5 × 10²³ cm⁻². The photon index is in agreement with previous studies on this source; on the contrary, a clear variation in the column density parameters free to vary in our fit, to check whether a possible variation may have been occurred in the 1.5 months monitoring. The best-fitting values of the five different NH do not show any significant variation with respect to the best-fitting value for the whole data set (9.0 ± 0.5 × 10²³ cm⁻²) with a non-significant improvement of the fit (Δχ² = 5 with four more parameters and a significance lower than 8 per cent). This result brings further evidence to the argument that absorption variability on short time-scales (hours–days) can be ruled out in our analysis of NGC 4507. If the intervening absorbing material had varied on such short time-scales, we would not have measured a constant column density in a 1.5 months monitoring. The measured values would have been completely scattered over the range of values observed in the past (4–9 × 10²³ cm⁻²).

### 3.2 Chandra ACIS spectral analysis

The baseline model is the same we used to fit the XMM–Newton data. The overall fit is very good (χ² = 327/329) and the addition of a further emission line at 1.81 ± 0.02 keV is required (Δχ² = 14 with a significance greater than 99.99 per cent), with a flux of 4.1±1.5 × 10⁻⁶ ph cm⁻² s⁻¹, marginally consistent with the emission from Si Kα already found in XMM–Newton best fits. The soft X-ray spectrum is produced by two photoionized phases, while the contribution by a collisional gas is not required by the fit. Equivalent widths, fluxes and energy centroids of the emission lines found in the 5–7.5 keV energy range are fully consistent with the results reported above. Best-fitting values are shown in Table 1 and the column is labelled as Obs. 6.

The reflected primary continuum has been fitted as described before (see Section 3.1): the best-fitting value of the absorbing

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Table 1. Best-fitting values. Energies are in keV, line fluxes in 10⁻⁵ ph cm⁻² s⁻¹ and EWs in keV. Photoionization parameters log U₁, log U₂ and column densities log NH₁, log NH₂ are the best-fitting values of the two photoionized phases needed to reproduce the soft emission; kT is the energy of the additional collisional phase (see the text for detail).

| Parameter | Obs. 1 | Obs. 2 | Obs. 3 | Obs. 4 | Obs. 5 | Obs. 6 | Set 1 |
|-----------|-------|-------|-------|-------|-------|-------|-------|
| K (PN-MOS) | 0.99±0.02 | 1.06±0.03 | 1.02±0.03 | 1.02±0.03 | 0.93±0.03 |       |       |
| N_H (10²³ cm⁻²) | 8.7±0.7 | 9.7±0.9 | 7.6±1.0 | 9.4±1.1 | 8.0±0.8 | 6.5±0.7 | 9.0±0.5 |
| Γ | 1.8±0.3 | 2.0±0.3 | 1.4±0.3 | 1.9±0.3 | 1.6±0.4 | 1.5±0.4 | 1.8±0.2 |
| F (CS₂) [eV] | <1.5 | <1.7 | 1.8±0.7 | 1.4±0.7 | 0.8±0.4 | 2.0±0.9 | 1.0±0.2 |
| Fe Kα | 6.40±0.01 | 6.40±0.01 | 6.41±0.02 | 6.41±0.01 | 6.40±0.02 | 6.40±0.02 | 6.40±0.003 |
| Flux | 4.4±0.3 | 3.6±0.5 | 3.7±0.7 | 4.3±0.7 | 4.6±0.5 | 4.0±1.0 | 4.2±0.3 |
| EW [250] | 315±35 | 250±40 | 245±35 | 285±35 | 335±35 | 220±30 |
| Fe Kβ | 7.058 | 7.058 | 7.058 | 7.058 | 7.058 | 7.058 |
| Flux | <0.6 | <0.5 | <0.6 | <0.5 | <0.8 | <1.1 | 0.3±0.2 |
| EW | <50 | <35 | <45 | <40 | <70 | <70 |
| Fe xxv E | 6.700 | 6.700 | 6.700 | 6.700 | 6.700 | 6.700 |
| Flux | 0.6±0.3 | <0.3 | 0.7±0.4 | <0.7 | <0.3 | <0.4 | 0.3±0.1 |
| EW | 40±20 | 25±25 | <20 | 45±25 | <45 | <20 | <20 |
| kT (keV) | 0.43±0.12 | 0.5±0.10 | 0.44±0.26 | 0.43±0.17 | 0.42±0.12 |       | 0.43±0.11 |
| log U₁ | 1.63±0.05 | 1.59±0.10 | 1.75±0.05 | 1.59±0.11 | 1.67±0.07 | 1.85±0.20 | 1.64±0.04 |
| log N_H₁ | 20.5±0.2 | 20.9±0.3 | 20.9±0.2 | 21.1±0.4 | 20.8±0.4 | 21.9±0.8 | 21.0±0.1 |
| log U₂ | −0.69±0.10 | −0.18±0.28 | −0.45±0.30 | −0.47±0.64 | 0.30±0.30 | 0.90±0.10 | −0.15±0.21 |
| log N_H₂ | 19.9±0.1 | 20.4±0.5 | <19.8 | 19.8±0.5 | 19.9±0.3 | 21.5±0.1 | 19.9±0.3 |
| F₁0.1–2 keV | 0.4±0.1 | 0.4±0.1 | 0.4±0.2 | 0.4±0.1 | 0.4±0.1 | 0.3±0.2 |       |
| F₁2–10 keV | 7.7±0.3 | 8.0±0.3 | 8.4±0.2 | 8.0±0.3 | 7.5±0.8 | 10.0±0.4 |       |
| χ²/dof | 308/292 | 347/268 | 242/272 | 267/267 | 280/283 | 313/327 | 1576/1459 |

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1 The F-test is not a reliable test for the significance of emission lines unless their normalizations are allowed to be negative (Protassov et al. 2002).
A clear changing look on time-scales of years has been already discussed in B12, while for the first time a column density variation has been observed on time-scales of months. (b) Column density light curve from 2010 June to December. The five XMM–Newton observations do not show any evidence of variation in $N_H$, while the Chandra value clearly differs from the XMM combined best-fitting value, which is plotted as a red solid line with errors as red dashed lines.

column density is $6.5 \pm 0.7 \times 10^{23}$ cm$^{-2}$, leading to a $2.5 \times 10^{23}$ cm$^{-2}$ variation at a 3σ confidence level in a time-scale ranging between 1.5 (time interval between the first and the fifth XMM–Newton observation) and 4 months (time interval between the last XMM–Newton observation and the one with Chandra). In Fig. 3, we show the influence of the change in $N_H$ on the spectral shape between 3 and 10 keV. Considering the partial degeneracy between the column density and the spectral slope, the significance of the variation is even stronger, as illustrated by the $\Gamma$–$N_H$ contour plots shown in Fig. 4.

4 PHYSICAL DISCUSSION

From the X-ray data analysis presented above, a column density variation in a time-scale of months is evident. We are going to describe, in the following, the physical implications of this result. Changes in absorbing column density are due to two different physical processes: a variation of the ionizing primary radiation, which causes the variation in the ionization state of the absorber or variations in the amount of absorbing gas along the line of sight. In the case of NGC 4507, the first physical scenario can be clearly ruled out because the difference in the 2–10 keV fluxes between the observations is not significant enough to justify a variation in the primary ionizing radiation.

The black hole mass of NGC 4507 is estimated by means of stellar velocity dispersion to be $4.5 \times 10^7$ M$_\odot$ (Marinucci et al. 2012b). We assume the dimensions of the X-ray emitting source $D_S$ to be $10 R_G$. This is in agreement with continuum variability studies and disc-corona emission models, all suggesting a compact central X-ray source, confined within a few $R_G$ from the central black hole. We also assume that the size of the obscuring cloud $D_C \sim D_S$. A schematic view of the geometrical structure is shown in Fig. 5. The transverse velocity $v_K$ for one obscuring cloud is then simply given by the linear dimension of the X-ray source, $D_S$, divided by the crossing time $T_{cr}$:

$$v_K = \frac{D_S}{T_{cr}} \approx \frac{10 G M_{bh}}{c^2 T_{cr}} \approx 70 \text{ km s}^{-1} M_{\odot}^{-1} T_{4}^{-1},$$

where we introduced the adimensional parameters $M_{\odot} = M_{bh}/10^7 M_\odot$ and $T_{4} \approx 1 \times 10^7$ $s \approx 4$ months.
The obscuring clouds’ velocities we measured (70–170 km s\(^{-1}\)) are at least one order of magnitude smaller than the typical BLR clouds’ velocities. The absorption variability is due to circumnuclear material which is located at distances consistent with the putative torus (Antonucci 1993). Such material cannot be located at much larger scales (i.e. dust lanes), since the NLR is not significantly affected by reddening, as inferred by the observed H\(\alpha\)/H\(\beta\) ratio (Kewley et al. 2001).

Since the presence of a Compton-thick material around the nucleus is invariably accompanied by a neutral iron narrow K\(_\alpha\) emission line and a cold reflection emission, it is interesting to point out the fact that the spatial scale of the obscuring material in NGC 4507 is consistent with the distance of the reflector observed with Chandra in the nearby Compton-thick Seyfert 2 NGC 4945 (Marinucci et al. 2012a).

The existence of a more complex structure surrounding the central engine of AGN rather than the one predicted by the unification model has been proposed and widely discussed in the past few years (Maiolino & Rieke 1995; Elvis 2000; Matt 2000) and recently in Bianchi et al. (2007), Risaliti & Elvis (2010), Bianchi, Maiolino & Risaliti (2012) and Elvis (2012).

Accordingly to these models, only absorbing matter on very different scales can be responsible for the wide phenomenology of column density variations, leading to an overall scenario where different absorbers/reflectors are responsible for the spectral changes in the Seyfert 2 galaxies observed so far.

The column density variation we measured in NGC 4507 is a further piece that can be added to the puzzle. In our analysis the lack of any variation on short time-scales (hours, days) excludes an absorber located in the BLR while the change on time-scales of months leads to an absorber much farther from the X-ray source, differently with respect to other variable objects (e.g. NGC 1365, NGC 4151, UGC 4203; Risaliti et al. 2005, 2007, 2009; Puccetti et al. 2007; Risaliti et al. 2010) on long time-scales (months, years) and rapidly changing on short ones observed so far. Our analysis provides further evidence that a universal circumnuclear structure of absorbing matter is therefore not suited for taking into account all the observed phenomenology on absorption variability in AGN. While it is true that absorption must occur on different scales, not all the objects present evidence of absorption from all the possible scales.

5 CONCLUSIONS

We reported in this paper the analysis of five XMM–Newton observations spanning a period of 6 weeks and a Chandra observation performed 4 months afterwards of the obscured AGN in NGC 4507. This source had shown strong column density variations in time-scales of years (from 1990 until 2007) and none in shorter time-scales during the 3 d of Suzaku monitoring. We therefore investigated time-scales ranging from 1.5 up to 4 months, looking for absorbing structures located farther from the innermost X-ray source.

Our results can be summarized as follows.

(i) A column density variation of \(\Delta N_{\text{HII}} = 2.5 \times 10^{23} \text{ cm}^{-2}\) at a 3\(\sigma\) confidence level on a time interval between 1.5 and 4 months has been measured. Such time-scales lead to distances of the absorber ranging from \(R = 7 \times 10^{22} \text{ cm} \times M_{\text{BLR}}^{-1/2} \text{ pc} \) with corresponding velocities of 70–170 km s\(^{-1}\) \(M_{\text{BLR}}^{-1/2}\). These distances imply that the obscuring material is located well outside the BLR, and suggest a much more complex environment of absorbing structures.

![Figure 5. Schematic view of the circumnuclear absorbing structure.](image-url)
The distances we inferred suggest that a single, universal structure of the absorber is not enough to reproduce the X-ray absorption variability of this AGN. Different reflectors/absorbers are responsible for the observed X-ray features.

In the near future, following the results presented in Risaliti (2002), a monitoring of all the sources that have shown changes on timescales of years but none on shorter (hours–days) can be performed. A broad-band, time-resolved study of AGN is fundamental for a better understanding of the complex circumnuclear material and its interaction and response to the primary radiation.

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REFERENCES

Anders E., Grevesse N., 1989, Geochim. Cosmochim. Acta, 53, 197
Antonucci R., 1993, ARA&A, 31, 473
Arnaud K. A., 1996, in Jacoby G. H., Barnes J., eds, ASP Conf. Ser. Vol. 101, Astronomical Data Analysis Software and Systems V, xspec: The First Ten Years. Astron. Soc. Pac., San Francisco, p. 17
Awaki H., Kunieda H., Tawara Y., Koyama K., 1991, PASJ, 43, L37
Bianchi S., Guainazzi M., 2007, in di Salvo T., Israel G. L., Piersanti L., Burderi L., Matt G., Tornambe A., Menna M. T., eds, AIP Conf. Ser. Vol. 924, The nature of the soft X-ray emission in obscured AGN. Am. Inst. Phys., New York, p. 822
Bianchi S., Guainazzi M., Chiaberge M., 2006, A&A, 448, 499
Bianchi S., Chiaberge M., Piconcelli E., Guainazzi M., 2007, MNRAS, 374, 697
Bianchi S., Piconcelli E., Chiaberge M., Bailón E. J., Matt G., Fiore F., 2009, ApJ, 695, 781
Bianchi S., Chiaberge M., Evans D. A., Guainazzi M., Baldi R. D., Matt G., Piconcelli E., 2010, MNRAS, 405, 553
Bianchi S., Maiolino R., Risaliti G., 2012, Adv. Astron., 2012, id. 782030
Braito V., Ballo L., Reeves J. N., Ptak A., Risaliti G., Turner T. J., 2012, arXiv-e-prints (B12)
Comastri A., Vignali C., Cappi M., Matt G., Audano R., Awaki H., Ueno S., 1998, MNRAS, 295, 443
Dickey J. M., Lockman F. J., 1990, ARA&A, 28, 215
Elvis M., 2000, ApJ, 545, 63
Elvis M., 2012, in Chartas G., Hamann F., Lehty L. M., eds, ASP Conf. Ser. Vol. 460, Quasar Structure Emerges from the Three Forms of Radiation Pressure. Astron. Soc. Pac., San Francisco, p. 186
Elvis M., Risaliti G., Nicastro F., Miller J. M., Fiore F., Puccetti S., 2004, ApJ, 615, L25
Fruscione A. et al., 2006, Proc. SPIE, 6270, 62701V
Gabriel C. et al., 2004, in Ochsenbein F., Allen M. G., Egret D., eds, ASP Conf. Ser. Vol. 314, The XMM–Newton SAS – Distributed Development and Maintenance of a Large Science Analysis System: A Critical Analysis. Astron. Soc. Pac., San Francisco, p. 759
Garmire G. P., Bautz M. W., Ford P. G., Nousek J. A., Ricker G. R., 2003, Proc. SPIE, 4851, 28
Guainazzi M., Bianchi S., 2007, MNRAS, 374, 1290
Kewley L. J., Heisler C. A., Dopita M. A., Lumsden S., 2001, ApJS, 132, 37
Kriss G. A., Canizares C. R., Ricker G. R., 1980, ApJ, 242, 492
Krolik J. H., Begelman M. C., 1988, ApJ, 329, 702
Magdziarz P., Zdziarski A. A., 1995, MNRAS, 273, 837
Maiolino R., Rieke G. H., 1995, ApJ, 454, 95
Marinucci A., Bianchi S., Matt G., Fabian A. C., Iwasawa K., Miniutti G., Piconcelli E., 2011, A&A, 526, A36
Marinucci A., Bianchi S., Nicastro F., Matt G., Goulding A. D., 2012b, ApJ, 748, 130
Matt G., 2000, A&A, 355, L31
Matt G., 2002, MNRAS, 337, 147
Matt G., Bianchi S., D’Ammando F., Martocchia A., 2004, A&A, 421, 473
Nardini E., Risaliti G., 2011, MNRAS, 417, 2571
Osterbrook D. E., 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei. University Science Books, Mill Valley
Piconcelli E., Jimenez-Bailón E., Guainazzi M., Schartel N., Rodríguez-Pascual P. M., Santos-Lleo M., 2004, MNRAS, 351, 161
Protassov R., van Dyk D. A., Connors A., Kashyap V. L., Siemiginowska A., 2002, ApJ, 571, 545
Puccetti S., Fiore F., Risaliti G., Capalbi M., Elvis M., Nicastro F., 2007, MNRAS, 377, 607
Risaliti G., 2002, A&A, 386, 379
Risaliti G., Elvis M., 2010, A&A, 516, A89
Risaliti G., Elvis M., Nicastro F., 2002, ApJ, 571, 234
Risaliti G., Elvis M., Fabbiano G., Baldi A., Zezas A., 2005, ApJ, 623, L93
Risaliti G., Elvis M., Fabbiano G., Baldi A., Zezas A., Salvati M., 2007, ApJ, 659, L111
Risaliti G. et al., 2009, ApJ, 696, 160
Risaliti G., Elvis M., Bianchi S., Matt G., 2010, MNRAS, 406, L20
Smith R. K., Brickhouse N. S., Liedahl D. A., Raymond J. C., 2001, ApJ, 556, L91
Strüder L. et al., 2001, A&A, 365, L18
Turner T. J., George I. M., Nandra K., Mushotzky R. F., 1997, ApJ, 113, 23T
Turner M. J. L. et al., 2001, A&A, 365, L27

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