Acta Polytechnica **53**(Supplement):793–798, 2013
doi:10.14311/AP.2013.53.0793

EROSITA: AGN SCIENCE, BACKGROUND DETERMINATION, AND OPTICAL FOLLOW-UP SPECTROSCOPY

Thomas Boller*

Max-Planck-Institut für extraterrestrische Physik, PSF 1312, 85741 Garching, Germany

* corresponding author: bol@mpe.mpg.de

Abstract. More than 20 years after the highly impacting ROSAT all-sky survey in the soft X-ray spectral range, we are close to the next major X-ray all/sky surveys with eROSITA. eROSITA will be the primary instrument on-board the Russian "Spectrum–Roentgen–Gamma" (SRG) satellite which will be launched from Baikonur in 2014 and placed in an L2 orbit. It will perform the first imaging all-sky survey in the medium energy X-ray range up to 10 keV with an unprecedented spectral and angular resolution. The eROSITA all sky X-ray survey will take place in a very different context than the ROSAT survey. There is now a wealth of complete, ongoing and planned surveys of the sky in broad range of wavelengths from the gamma, X-ray to the radio. A significant amount of science can be accomplished through the multi-frequency study of the eROSITA AGN and cluster sample, including optical confirmation and photometric redshift estimation of the eROSITA extended sources and AGNs. Optical spectroscopy has been, and will for the foreseeable future be, one of the main tools of astrophysics allowing studies of a large variety of astronomical objects over many fields of research. The fully capitalize on the eROSITA potential, a dedicated spectroscopic follow-up program is needed. 4MOST is the ideal instrument to secure the scientific success of the eROSITA X-ray survey and to overcome the small sample sizes together with selection biases that plagued past samples. The aim is to have the instrument commissioned in 2017, well matched to the data releases of eROSITA and Gaia. The design and implementation of the 4MOST facility simulator aimed to optimize the science output for eROSITA is described in necessary details.

Keywords: X-ray mission: new, spectroscopy.

1. eROSITA AGN science

eROSITA will be the primary instrument on-board the Russian "Spectrum–Roentgen–Gamma" (SRG) satellite which will be launched from Baikonur in 2014 and placed in an L2 orbit (see [1] for the most recent update). eROSITA offers a unique possibility to understand the AGN phenomenon more generally by extending AGN observations within an All-Sky Survey and subsequent detailed pointed observations.

1.1. Relativistic Fe K emission lines, the strong field limit and black hole spin determination

The study of relativistically broadened Fe K lines in AGNs can be used as a diagnostic tool of the geometry of the accreting matter at the innermost stable orbit as well as of the spin of the black hole. Since the discovery of optically thick matter in the vicinity of a black hole in the form of a Fe K line [2–4] and resolving the relativistic Fe K line in MCG–6-30-15 [5], broad iron lines have been found so far only in a few other Seyfert galaxies [6]. A recent study of NLS1 galaxies revealed emission very close to the central black hole in three prototype objects, confirming the presence of soft X-ray reflection and moderate black hole spin values [7].

eROSITA, both during its survey and pointing operations will offer a unique possibility to further study the behavior of matter under strong gravity on a much larger sample of AGNs showing relativistic line emission. These studies are of long term importance for identifying complete samples for more detailed studies by future X-ray missions like Athena [9]. These studies have to be accompanied by e.g. ground based optical surveys and spectroscopy to uniquely identify the source type.

1.2. eROSITA black hole growth studies and multi-wavelength follow-up work

The study of the black hole growth over cosmic time is one of the key science issues which are of relevance for the core science of the eROSITA mission. Narrow-Line Seyfert 1 (NLS1) galaxies with their proven high accretion rates exceeding the Eddington limit by a factor of $10 \div 20$ are most probably the objects with the highest black hole growth rates in the nearby universe are therefore ideally suited for such studies. While LINER galaxies accrete at very low rates of their Eddington accretion rates with values ranging from about $10^{-6 \div 2}$ [10], the accretion rate is increasing with decreasing masses of the black hole. Kollmeier et al. [11] have studied the Eddington luminosity ratios of broad line AGN and found a relatively narrow scatter in the Eddington accretion rates of 0.3 dex with a peak at about 0.25. NLS1 galaxies exhibit the lowest black hole masses and the highest accretion rates [12, 13]. The most probable explanation for this trend is that NLS1 galaxies are AGNs just in the forming (e.g. Mathur 2000) with low black holes masses and still a lot of gas reservoir to feed the black hole. In addition, intense star forming processes are expected which yield to the enrichment of the circumnuclear material with metals. The black hole growth due to accretion is expected to be the fastest in NLS1 galaxies. Studying the accretion rate and the observational properties of NLS1 galaxies with eROSITA provide a unique possibility to search for signatures of rapid black hole growth. The black hole growth due to accretion results in changes in the observational parameters of AGNs.

The FWHM of the permitted lines of the BLR will increase with time and it is inversely correlated with the accretion rate. An increasing black hole mass will result into a lower ionizing continuum, flatter soft and hard X-ray continua and a higher emissivity from the NLR. Optical and near infrared spectroscopic follow up work is essential here to uniquely apply the definition for NLS1 galaxies based on their optical Fe II multiplet emission and narrow H β FWHM line widths [14].

Basically, this connects the NLS1 research to a large scale spectroscopic survey, which is a challenging and crucial aspect for the eROSITA mission. All these parameters changes will be tested by studying especially NLS1 galaxies with eROSITA over a substantial amount of cosmic time. Confirming the black hole growth and the change in the observational parameters over the life time of active galaxies in their NLS1 phase will be of importance for the astrophysical community at large.

With the capabilities of eROSITA we will achieve an important step forward in understanding growing black holes in a cosmological context.

1.3. Accretion disc physics and NLS1 science

XMM-Newton observations appear to have decomposed the X-ray spectra of AGN into a strong, relativistically blurred reflection plus power law component (e.g. [15]). While the relativistic reflection model appears to be supported by the detection of both Fe K and Fe L emission with a normalization of the photon flux in the ratio of 20:1 in 1H 0707−495, in agreement with atomic physics and the presence of a 30 s time delay between the soft and hard light curves [16], the modelling of the high energy parts of the spectra might require further improvements to account for the sharp spectral drops in 1H 0707−495 [17, 18] and IRAS 13224−3809 [19]. Recently Miller et al. [20] have questioned the reverberation interpretation associated with the inner disc. Their results are consistent with a partial covering interpretation of a substantial fraction of scattered X-rays passing through an absorbing medium whose opacity decreases with increasing energy. It is argued that both absorption and scattering is required and that the X-ray emitting material might be associated with an accretion disc wind. Further modelling and observations are required to make progress. The eROSITA all-sky survey and pointed observations will open a new window on the study of NLS1 galaxies. As ROSAT and XMM-Newton provided new and fascinating observational results on NLS1 galaxies, the further study of this class will be striking in terms of even more exciting discoveries.

2. Synergy between eROSITA and multi-frequency missions

The eROSITA all sky X-ray survey will take place in a very different context than the ROSAT survey. There is now a wealth of complete, ongoing and planned surveys of the sky in broad range of wavelengths from the gamma, X-ray to the radio. A significant amount of science can be accomplished through the multi-frequency study of the eROSITA AGN and cluster sample, including optical confirmation and photometric redshift estimation of the eROSITA extended sources and AGNs. The SDSS survey is already public in the north and will provide excellent confirmation and redshift estimation of extended sources out to redshifts approaching $z = 0.5$. The Pan-STARRS1 survey will push around 0.75 magnitudes deeper than SDSS and over a larger fraction of sky, allowing studies of clusters and AGN over essentially the full northern sky. The first two large aperture, large solid angle multiband optical surveys, the Dark Energy Survey in the south and the Hyper Suprime-Cam Survey in the north, will also be underway as the eROSITA data come on. Both surveys will enable cluster confirmation and cluster and AGN photometric redshift estimation out to $z = 1$ and beyond. The DES survey is also coupled to a deep NIR survey with VISTA (Visible and Infrared Survey Telescope for Astronomy) that should further extend the redshift grasp of the eROSITA mission. These datasets will be available, either publicly or through targeted partnerships, but it will require a significant effort to couple them to the eROSITA source lists. But the scientific payoff in studies of large scale structure, cluster and AGN populations and constraints on the cosmic acceleration will be profound.

In addition, a large scale spectroscopic survey would deliver additional new science, including precise cluster redshifts to enrich large scale structure and cosmology studies as well as AGN spectra that provide direct constraints on the physical state of the gas surrounding the central black holes in unobscured eROSITA X-ray sources. A large scale spectroscopic survey is a challenging and crucial aspect for eROSITA and the 4MOST (4-meter Multi-Object Spectroscopic Telescope) will play a very important role in the follow-up observations of eROSITA AGNs and eROSITA clusters.

Other surveys like Fermi, Planck and the SPT will enable X-ray and SZE studies of clusters of galaxies and AGNs. LSST (Large Synoptic Survey Telescope) will provide much deeper data once it comes along with respect to the DES and the HSC. For ALMA AGN studies in great detail are expected. SKA (Square Kilometre Array) will constrain the galaxy evolution of gas-rich galaxies out to $z = 1$, will probe matter in the strong field limit using black holes and pulsars, and will use the hydrogen emission from galaxies to measure the properties of Dark Energy. These surveys will be very complementary to eROSITA and therefore of general interest for the synergy aspect. The multi-frequency approach is one of the key science drivers for the eROSITA mission.

3. eROSITA background determination

The eROSITA background has been simulated based on photon and high-energy particle spectral components. The cosmic diffuse photon X-ray background has been adopted from Lumb et al. 2011 [1] and the high-energy particle background, which does not interact with the mirror system has been calculated by Tenzer et al. [21]. The expected background count rate has been compared with XMM-Newton observations, which might provide the best test for the X-ray background for eROSITA around the Lagrangian point L2 before real X-ray background data will become available.

3.1. Spectral components included in the eROSITA background simulations

3.1.1. The photon X-ray background

The photon X-ray background has been modeled based on the assumption made by Lumb et al. 2011. The photon X-ray background originates from two major components, the optically thin diffuse emission and the extragalactic unresolved background emission. The optically thin diffuse emission arises from the Local Hot Bubble, the Galactic Disk and the Galactic Halo. The optically thin background emission from these components are modeled with two *mekal* models (an emission spectrum from hot diffuse gas, cf. [22]) with temperatures of $kT_1 = 0.204\,\mathrm{keV}$, and $kT_2 = 0.074\,\mathrm{keV}$. The corresponding normalizations are $n_1 = 7.59\,\mathrm{photons\,keV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}}$, and $n_2 = 116.0\,\mathrm{photons\,keV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}}$, respectively. The extragalactic unresolved background emission is modeled with a power law model with a photon index Γ of 1.42 and a normalization of $n = 9.03\,\mathrm{photons\,keV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}}$.

3.1.2. The high energy particle background

The high energy particle background has been modeled according to C. Tenzer et al. [21] based on Geant4 simulation studies of the eROSITA detector background. The high energy particle background which is not interacting with the mirrors is modeled with a flat power law model with a photon index Γ of 0.0 and a normalization of $n = 1151\,\mathrm{photons\,keV^{-1}\,s^{-1}\,sr^{-1}}$.

3.2. Comparison of the simulated eROSITA photon and particle background with the observed XMM-Newton background

Table 1 shows the comparison between the observed XMM-Newton count rate for the medium filter (without particle background, cf. Table 7 of [23]) and the simulated photon plus particle eROSITA background count rates. The overall diffuse cosmic photon X-ray emission from the Lumb et al. 2011 model is in good agreement with the observations obtained by XMM-Newton. At energies above 5 keV the high energy particle background dominates the spectral energy distribution of the simulated eROSITA background.

Based on the spectral model parameters described above the mean eROSITA background count rate model is shown in Fig. 1.

4. eROSITA optical follow-up spectroscopy with 4MOST

Optical spectroscopy has been, and will for the foreseeable future be, one of the main tools of astrophysics allowing studies of a large variety of astronomical objects over many fields of research. The fully capitalize on the eROSITA potential, a dedicated spectroscopic follow-up program is needed. 4MOST is the ideal instrument to secure the scientific success of the X-rays surveys and to overcome the small sample sizes together with selection biases that plagued past samples. The aim is to have the instrument commissioned in 2017, well matched to the data releases of eROSITA and Gaia. Here I shortly describe the design and implementation of a facility simulator aimed to optimize the science output for eROSITA. The 4MOST Facility Simulator (4FS) has several roles, firstly to optimize the design of the instrument, secondly to devise a survey strategy for the wide field design reference surveys that are proposed for 4MOST, and thirdly to verify that 4MOST, as designed, can indeed achieve its primary science goals.

In order to optimize the science output from 4MOST a dedicated simulation software, the 4MOST Facility Simulator (4FS) has been developed [24]. The 4FS will not only optimize the science output from 7 Design Reference Surveys (DRS), two of them, the AGN and the Cluster DRS, are dedicated for eROSITA follow-up, but it also used to understand and optimize the instrument behavior. The 4FS consists of three different major components, the Operations Simulator (OpSim), the Throughput Simulator (TS), and the Data Quality Control Tools (DQCT), each of which have specified tasks. The OpSim component is located

---

[1] `http://arxiv.org/abs/astro-ph/0204147`

Energy band [keV]	0.2 ÷ 0.5	0.5 ÷ 2.0	2.0 ÷ 4.5	4.5 ÷ 7.5	7.5 ÷ 12
simulated particle count rate [10^{-3} counts s^{-1} arcmin^{-2}]	0.028	0.15	0.24	0.29	0.44
simulated photon and particle count rate [10^{-3} counts s^{-1} arcmin^{-2}]	1.71	2.19	0.36	0.31	0.44
observed XMM-Newton background PN medim filter [10^{-3} counts s^{-1} arcmin^{-2}]	1.13 ± 0.50	2.04 ± 0.94	0.72 ± 0.36	0.64 ± 0.36	0.68 ± 0.48

Table 1. Simulated eROSITA photon and particle count rates and the comparisions with the observed XMM-Newton background count rates.

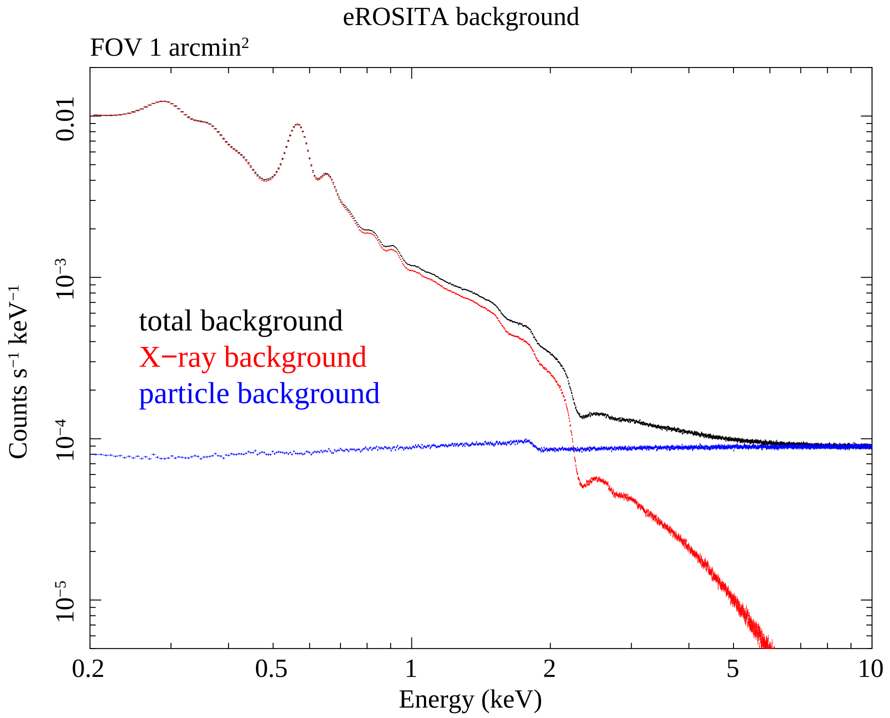

Figure 1. Mean eROSITA background spectrum (Boller, eROSITA Science book).

at MPE, Garching, the TS at GEPI, Paris, and the DQCT at IoA, Cambridge. Data flow between the major components is carried out over the Internet through an rsync directory system located at MPE, Garching. The 4FS accepts input data in the format of mock catalogues of targets, together with template spectra of targets. Each mock catalogue represents one DRS. The operation of 4FS is controlled through parameter files issued by the Systems Engineer, which define the set-up of each system that should be to be simulated.

Figure 2 illustrates, in a graphical way, the summary statistics internally generated by the 4FS OpSim for each simulation that has been carried out. The plot show the fraction of input objects that have been assigned a fiber in at least one tile of the simulated survey. Note that this is not the same measure as the fraction of input objects that were 'successfully' observed reported by the 4FS DQCT. However, the allocated fractions reported here do provide strong upper bounds on the successfully observed fractions. The survey footprint is defined as the locus of all points on the sky that lie within the hexagonal bounds of at least one field in which at least one tile was executed. Due to the FOV shape, the survey footprint has slightly 'ragged' Northern and Southern edges. Therefore, some points of the footprint extend slightly outside the nominal declination limits of the survey. The plots illustrate the relative ability of each combination of telescope, positioner, FOV, number of fibers, high/low resolution fiber pattern that has been simulated. The red bars show the fraction of objects within the survey footprint that were allocated a fiber in at least one tile. The blue bars show the frac-

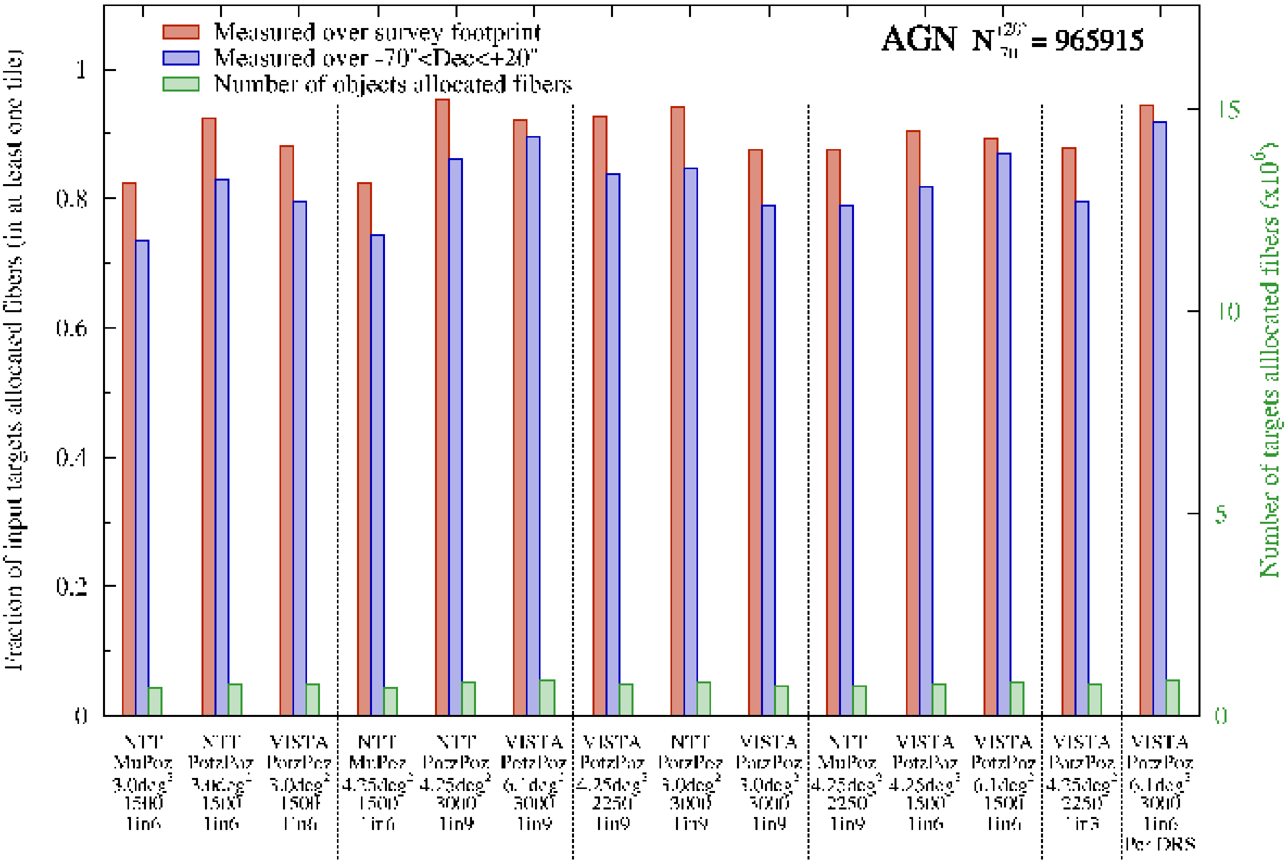

FIGURE 2. Fraction of input objects that have been assigned a fiber in at least one tile of the simulated AGN survey [24]. 14 individual combination of a telescope selection, NTT or VISTA, and Fiber Positioner Concepts, the Potsdam Position (Potzpos) and the Munich Positioner (MuPos), have been simulated. Other parameters that have been varied are the FOV of the telescope, the number of high and low resolution fibers and the ratio between high and low resolution fibers. See [24] for a detailed description of the 4FS simulation for telescope trade off selection.

tion of all input objects (within the declination limits $-70° < \mathrm{Dec} < +20°$) that were allocated a fiber in at least one tile. The total number of objects within the $-70° < \mathrm{Dec} < +20°$ range is given in the top right hand corner of the plot. The red and blue bars should be read off against the left hand y-axis scale. The green bars show the number of objects that were allocated a fiber in each simulation, with a scale that should be read off the right hand y-axis. Note that the blue bar is simply the number of sources allocated fibers (indicated by the green bar) divided by the total number of objects, indicated in the top right hand corner of each plot. The allocation fraction for the eROSITA AGN mock catalogue is best for large FOVs for NTT and VISTA and for both types of Positioner Concepts. A complete description of the allocation fraction for the other DRS is given in [24].

ACKNOWLEDGEMENTS

TB is grateful to the Peter Predehl, the PI of eROSITA, for intensive discussions in preparation of the eROSITA talk given at the 2012 Vulcano workshop.

REFERENCES

[1] Merloni, A., Predehl, P., Becker, W., Böhringer, H., Boller, Th. et al., astro-ph, arXiv:1209.3114, 2012

[2] Nandra, K., Pounds, K. A., Stewart, G. C. et al., MNRAS 236, 39, 1989

[3] Pounds, K. A., Nandra, K., Stewart, G. C. et al., Nature 344, 132, 1990

[4] Nandra, K., Pounds, K. A., MNRAS 268, 405, 1994

[5] Tanaka, Y., Nandra, K., Fabian, A. C. et al., Nature 375, 659, 1995

[6] Nandra, K., O'Neill, P. M., George, I. M. et al., MNRAS 382, 194, 2007

[7] Boller, Th., Exploring Fundamental Issues in Nuclear Physics: Nuclear Clusters – Superheavy, Superneutronic, Superstrange, of Anti-Matter. Edited by Debades Bandyopadhyay (Saha Institute of Nuclear Physics, India). Published by World Scientific Publishing Co. Pte. Ltd., 2012. ISBN 9789814355766, pp. 44–52, 2012a

[8] Boller, Th., *Soft X-ray reflection and strong and weak field limit determination in Narrow-Line Seyfert 1 Galaxies*, Exploring Fundamental Issues in Nuclear Physics, Proceedings of the Symposium on Advances in Nuclear Physics in Our Time, Ed. Debades Bandyopadhyay, World Scientific Publishing Co. Pte. Ltd., ISBN-13 978-981-4355-72-8, 2012

[9] Nandra, K., *ATHENA: The Advanced Telescope for High Energy Astrophysics*, In: The X-ray Universe 2011, Presentations of the Conference held in Berlin,

Germany, 27–30 June 2011. Available online at: `http://xmm.esac.esa.int/external/`, article id.022, 2011

[10] Balestra, I., Tozzi, P., Ettori, S. et al., A&A 462, 429, 2007

[11] Kollmeier, J. A., Onken, C. A., Kochanek, C. S. et al., ApJ 648, 128, 2006

[12] Boller, Th., Growing black holes: accretion in a cosmological context. Proceedings of the MPA/ESO/MPE/USM Joint Astronomy Conference held at Garching, Germany, 21–25 June 2004. A. Merloni, S. Nayakshin, R. A. Sunyaev (Eds.). ESO astrophysics symposia. Berlin: Springer, ISBN 3-540-25275-4, ISBN 978-3-540-25275-7, 2005, p. 170–174, 2005

[13] Tanaka, Y., Boller, Th., Gallo, L., Growing black holes: accretion in a cosmological context. Proceedings of the MPA/ESO/MPE/USM Joint Astronomy Conference held at Garching, Germany, 21–25 June 2004. A. Merloni, S. Nayakshin, R. A. Sunyaev (Eds.). ESO astrophysics symposia. Berlin: Springer, ISBN 3-540-25275-4, ISBN 978-3-540-25275-7, 2005, p. 290–295, 2005

[14] Osterbrock, D. E., Pogge, R. W., ApJ 297, 166, 1985

[15] Miniutti, G., Fabian, A. C., MNRAS 349,1435, 2004

[16] Fabian, A. C. et al., Nature 459, 540, 2009

[17] Boller, Th., Fabian, A. C., Sunyaev, R. et al., MNRAS 329, L1, 2002

[18] Zoghbi, A., Fabian, A. C., Uttley, P., Miniutti, G. et al., MNRAS 401, 2419, 2010

[19] Boller, Th., Tanaka, Y., Fabian, A. et al., MNRAS 343, L89, 2003

[20] Miller, L., Turner, T. J., Reeves, J. N. et al., MNRAS 408, 1928, 2010

[21] Tenzer, Ch., Warth, G., Kendziorra, E. et al., Proceedings of SPIE, 7742, 2010

[22] Mewe, R., Gronenschild, E.H.B.M., van den Oord, G.H.J., A&A, 62, 197, 1985

[23] Read, A. M., Ponman, T. J., A&A 409, 395, 2003

[24] Boller, Th., Dwelly, T., Böhringer H., Proceedings of SPIE 2012b, in press