AGN warm absorption with the ATHENA

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X-ray astronomy requires satellites to make progress in searching the distribution of hot matter in the Universe. Approximately 15 years period of time is needed for full construction of the flight instrument from the mission concept up to the launch. A new generation X-ray telescope ATHENA (the Advanced Telescope for High Energy Astrophysics) was approved by European Space Agency as a large mission with a launch foreseen in 2028. In this paper we show how microcalorimeter on the board of ATHENA will help us to study warm absorption observed in active galactic nuclei (AGN). We show that future observations will allow us to identify hundreds of lines from highly ionized elements and to measure Galactic warm absorption with very high precision.

1 Introduction

There is a general consensus based on high resolution X-ray data that the majority of Seyfert galaxies contain warm ionised absorbing gas on their line of sight. After the technical improvement of the observing X-ray instrumentation as *Chandra, XMM-Newton, Suzaku*, the extensive studies of the Warm Absorber (hereafter WA) in AGN were performed. Many narrow absorption lines from highly ionised elements, detected with the use of gratings, provided a big opportunity to study this warm gas; (Kaspi et al., 2001; Collinge et al., 2001; Kaastra et al., 2002; Behar et al., 2003; Netzer et al., 2003; Krongold et al., 2003; Yaqoob et al., 2003; Steenbrugge et al., 2003; Blustin et al., 2003; Różańska et al., 2004; Turner et al., 2004; Steenbrugge et al., 2005; Costantini et al., 2007; Winter & Mushotzky, 2010; Winter et al., 2012; Tombesi et al., 2013; Laha et al., 2014, and many other papers). Nevertheless, the number of detected lines were always limited to less than dozen due to limited energy resolution and small effective area of the instrument.

Directly from observations, it is concluded that the absorbing material is in the form of wind outflowing with velocities from tens to hundred km/s. Furthermore, ionic column densities of particular ions could be determined and they are typically of the order of 10^{15-18} cm^{-2}. Those densities correspond to the continuous change of ionization parameter ξ (see Eq. 1 for definition), which spans the range of a few decades, $\log(\xi) \sim -1$ up to 4 (ξ in erg cm s^{-1}).

Holczer et al. (2007) proposed to describe ionisation structure of the wind by showing absorption measure distribution (AMD) obtained by a derivative formula (Eq. 5 in their paper). These authors, for the first time, have shown that in the case of the source IRAS 13349+2438, AMD obtained from observations has deep minimum in column density that is consistent with the negligible absorption of gas with $\log(\xi)$ between 0.8 and 1.8. Such deep minima are present in AMD of other objects as well (see for instance Behar, 2009; Detmers et al., 2011; Stern et al., 2014), and they are interpreted as the observational evidence for thermal instability in a given ionisation and temperature regime.

Recently, Adhikari et al. (2015) have modelled the observed absorption measure distribution (AMD) in Mrk 509, which spans three orders of magnitude in ionization level with a single-zone absorber in pressure equilibrium. AMD is usually constructed from observations of narrow absorption lines in radio-quiet active galaxies with warm absorbers. Adhikari et al. (2015) have shown that the simplest way to fully reproduce the shape of AMD is to assume that the warm absorber is a single zone under constant total pressure. With this assumption the authors found theoretical AMD which matches the observed one determined by Detmers et al. (2011) on the basis of 600 ks RGS XMM-Newton spectrum of Mrk 509.

We are interested in answering the question about imporvements of the results which will be possible with a new generation X-ray telescope ATHENA (Nandra et al., 2013) as a large mission with a launch foreseen in 2028. The mission will be equipped with the single mirrors assembly made in Silicon Pore Optic technique with effective area ten times greater than any other working satellites. ATHENA will have two focal plane detectors, which will be used alternatively depending on the observational plan. X-IFU (X-ray Integral Field Unit) is a very innovative detector, in which a single pixel measures extremely small temperature difference caused by X-ray photon that enters into it. The photon energy will be measured with the very high precision as never before. The expected energy resolution is 2.5 eV at 1 keV. In combination with high effective area of the mirrors the amount of detected lines will increases to several dozens. The second detector, WFI (Wide Field Imager) will be built with conventional silicon pixels, but with modern electronics ensures rapid signal readout. It will be dedicated to make deep galaxy cluster surveys.

As a result of the ESA CDF (Concurrent Design Facility) analysis, the effective area of the mirror was reduced. In this paper we show, how spectra transmitted through ionized outflow in AGN will be detected by new set of mirror parameters. For this purpose, we use the new version of response files produced by ATHENA team[1] and delivered on March 2015. To simulate the data we use the modelled transmitted spectrum computed for the best fitted absorption measure distribution in case of Mrk 509.

2 The AMD model

The distribution of the absorbing column in the line of sight is often described as Absorption Measure Distribution (AMD). Almost always the large range of ionisation state of gas located on the line of sight towards observer is seen in AGN with the warm absorber. A few of absorption lines is detected in high resolution spectra of several AGN. For the detailed definitions and analysis how modelled AMD computed with the use of photoionisation code TITAN (Dumont et al., 2000) reproduces the observed AMD for Mrk 509, we address the reader to the recent paper by Adhikari et al. (2015). Here we present only the general idea of computing the final transmitted spectrum.

Mrk 509 with redshift of 0.034397 (Huchra et al., 1993), is one of the best studied local AGN, with exceptionally high luminosity L(1-1000 Ryd)=3.2×10^{45} erg s^{-1} classified as a Sy1 galaxy. The WA in this source was extensively studied with 600 ks RGS (reflection grating spectrometer) on board of *XMM-Newton* X-ray telescope (Detmers

[1] http://www.the-athena-x-ray-observatory.eu/

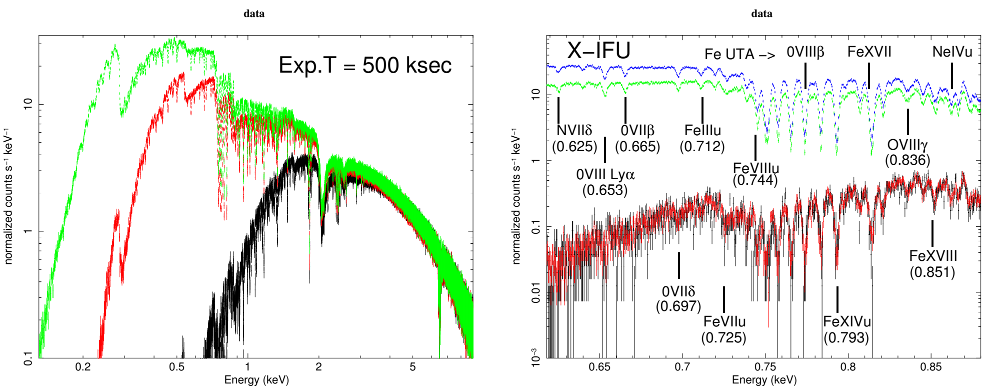

Fig. 1: Left panel shows simulated data for the exposure time 500 ksec, and for three different column densities responsible for Galactic absorption. Black color represents $N_{\rm H} = 10^{22}$, red – 10^{21}, and green – 10^{20} cm^{-2}. Right panel presents oxygen region for $T_{exp} = 200$ ksec. Here black color represents $N_{\rm H} = 10^{22}$, green – 10^{21}, and blue – 10^{20} cm^{-2}. In addition for the first column density higher exposure time equalled 500 ksec is presented by red line for comparison.

et al., 2011; Kaastra et al., 2012). The of absorption lines from higly ionized metals were identified, allowing for determination of ionic column densities. Furthermore, equivalent hydrogen column densities were calculated for each ion, and absorption measure distribution was constructed (Detmers et al., 2011).

Recently, very detailed observed continuum spectral shape of Mrk 509 was published by Kaastra et al. (2011). The SED of Mrk 509 covers a wide range of wavelength band, which is essential for obtaining the ionisation balance needed for photoionisation modelling. This spectral shape was used as an intrinsic radiation which illuminates the warm absorber. With above source luminosity the photoionisation calculations were performed assuming total pressure, $P_{\rm gas} + P_{\rm rad}$ to be constant. As a result the warm absorber continuously changes local ionization degree, which can be expressed due to the local ionization parameter:

$$\xi = \frac{L_{\rm ion}}{nR^2}, \tag{1}$$

where $L_{\rm ion}$ is the luminosity of the ionising source and n is the hydrogen number density. As a boundary conditions we define ξ at the cloud surface. But in phontoionization calculations, where radiation transfer is solved, we obtain ionization and density structure of the whole absorber. Resulting transmitted spectrum in the direction toward observer is used to make simulations for ATHENA X-IFU detector.

3 Simulations for X-IFU detector

The warm absorbers seen in AGN are the best targets to study with X-IFU/ATHENA detector. X-rays with energies above 0.1 keV interact with matter located on the line of sight toward observer producing many absorption lines from ionized heavy elements. Observations of these lines in the range from 0.1 up to 9 keV allow us precisely examine heavy elements content and their chemical evolution. Using XSPEC fitting package[2]

[2]https://heasarc.gsfc.nasa.gov/xanadu/xspec/

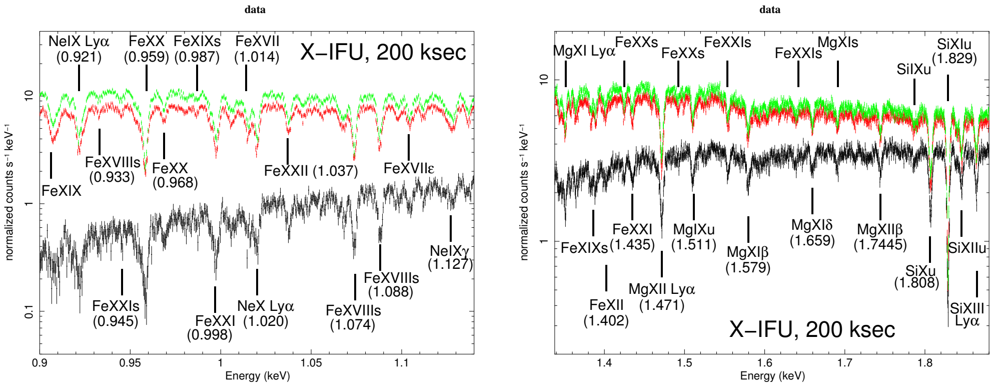

Fig. 2: Simulated data for the exposure time 200 ksec, and for three different column densities responsible for Galactic absorption. Black color represents $N_{\rm H} = 10^{22}$, red – 10^{21}, and green – 10^{20} cm^{-2}. Left panel shows the neon line region, while right panel presents absorption by magnesium.

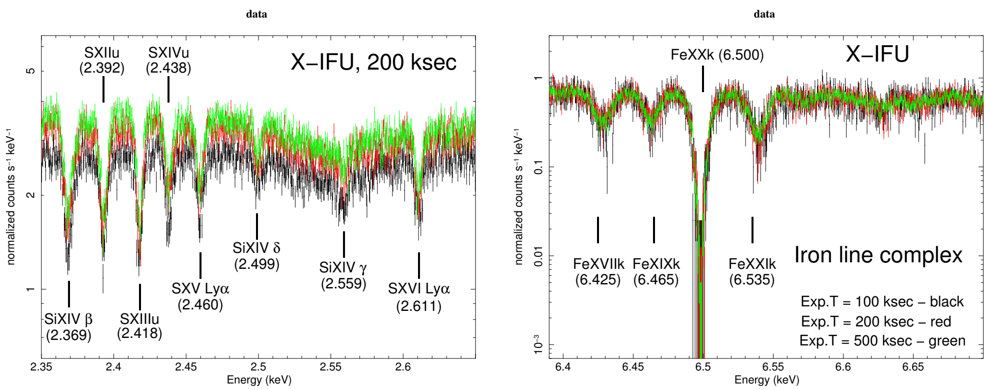

Fig. 3: Simulated data for the exposure time 200 ksec, and for three different column densities responsible for Galactic absorption. Black color represents $N_{\rm H} = 10^{22}$, red – 10^{21}, and green – 10^{20} cm^{-2}. Left panel shows the sulfur line region, while right panel presents absorption by iron.

we faked the transmitted warm absorber model with ATHENA response matrix to simulate observed data for three exposure times: 100, 200 and 500 ksec, and for three Galactic absorption values: $N_{\rm H} = 10^{22}, 10^{21}$, and 10^{20} cm^{-2}. The simulated data for different energy ranges are presented in Figs. 1, 2, and 3.

In the range of energies where possible absorption on highly ionized iron occurs, above ~ 6.4 keV, the influence of Galactic absorption is negligible. Note that some of those transitions are caused by fluorescence process, which is usually associated with the emission not absorption. In our data some energies of identified lines, marked by "k", are for fluorescent transition. Galactic absorption becomes important for the data towards lower energies. Nevertheless, the increase of exposure time does not improve the data as seen in Fig. 1, left panel – black and red data points.

In the next step, we made fitting of the simulated data with current model. The aim of such procedure is to show accuracy in determining the Galactic column density parameter from observations. Fig. 4 shows the confidence levels in determination of

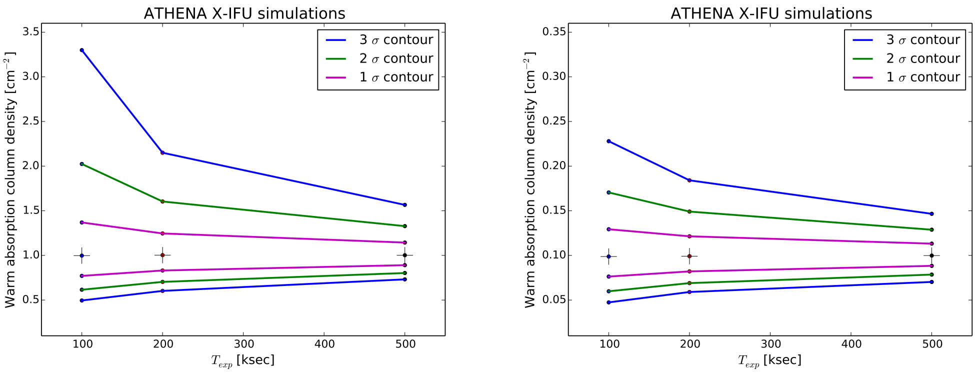

Fig. 4: Accuracy of determining the Galactic absorption in the procedure of fitting our model to the simulated data. Left panel shows the case for $N_{\rm H} = 10^{22}$ cm^{-2}, while right panel presents the case for $N_{\rm H} = 10^{21}$ cm^{-2}

Galactic absorption column density for one, two and three σ detection for two values of $N_{\rm H} = 10^{22}$ and 10^{21} cm^{-2} (left and right panel respectively). Both column densities will be well constrained with X-IFU detector. Increasing an exposure time above 200 ksec is not required to improve the fit.

ATHENA mission will increase the amount of absorption lines from AGN with warm absorbers. The high resolution of the X-IFU detector in combination with high effective area will allow us to determine absorption measure distribution for many other objects. Up to now, AMD was found only for seven AGN. Studying AMD in different sources will help us to understand the structure of the ionized outflows, their location and the mechanism which leads to their formation.

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References

Adhikari, T. P., Różańska, A., Sobolewska, M., Czerny, B., *Absorption Measure Distribution in Mrk 509*, ApJ **815**, 83 (2015), `1507.04035`

Behar, E., *Density Profiles in Seyfert Outflows*, ApJ **703**, 1346 (2009), `0908.0539`

Behar, E., et al., *A Long Look at NGC 3783 with the XMM-Newton Reflection Grating Spectrometer*, ApJ **598**, 232 (2003), `astro-ph/0307467`

Blustin, A. J., et al., *Multiwavelength studies of the Seyfert 1 galaxy NGC 7469 II. X-ray and UV observations with XMM-Newton*, A&A **403**, 481 (2003), `astro-ph/0302551`

Collinge, M. J., et al., *High-Resolution X-Ray and Ultraviolet Spectroscopy of the Complex Intrinsic Absorption in NGC 4051 with Chandra and the Hubble Space Telescope*, ApJ **557**, 2 (2001), `astro-ph/0104125`

Costantini, E., et al., *X-ray/ultraviolet observing campaign of the Markarian 279 active galactic nucleus outflow: a close look at the absorbing/emitting gas with Chandra-LETGS*, A&A **461**, 121 (2007), `astro-ph/0609385`

Detmers, R. G., et al., *Multiwavelength campaign on Mrk 509. III. The 600 ks RGS spectrum: unravelling the inner region of an AGN*, A&A **534**, A38 (2011), 1107.0658

Dumont, A.-M., Abrassart, A., Collin, S., *A code for optically thick and hot photoionized media*, A&A **357**, 823 (2000), astro-ph/0003220

Holczer, T., Behar, E., Kaspi, S., *Absorption Measure Distribution of the Outflow in IRAS 13349+2438: Direct Observation of Thermal Instability?*, ApJ **663**, 799 (2007), astro-ph/0703351

Huchra, J., et al., *The morphological catalogue of galaxies equatorial survey*, AJ **105**, 1637 (1993)

Kaastra, J. S., et al., *X-ray spectroscopy of NGC 5548*, A&A **386**, 427 (2002), astro-ph/0202481

Kaastra, J. S., et al., *Multiwavelength campaign on Mrk 509. I. Variability and spectral energy distribution*, *aap* **534**, A36 (2011), 1107.0656

Kaastra, J. S., et al., *Multiwavelength campaign on Mrk 509. VIII. Location of the X-ray absorber*, A&A **539**, A117 (2012), 1201.1855

Kaspi, S., et al., *High-Resolution X-Ray Spectroscopy and Modeling of the Absorbing and Emitting Outflow in NGC 3783*, ApJ **554**, 216 (2001), arXiv:astro-ph/0101540

Krongold, Y., et al., *Toward a Self-Consistent Model of the Ionized Absorber in NGC 3783*, ApJ **597**, 832 (2003), astro-ph/0306460

Laha, S., et al., *Warm absorbers in X-rays (WAX), a comprehensive high-resolution grating spectral study of a sample of Seyfert galaxies - I. A global view and frequency of occurrence of warm absorbers.*, MNRAS **441**, 2613 (2014)

Nandra, K., et al., *The Hot and Energetic Universe: A White Paper presenting the science theme motivating the Athena+ mission*, *ArXiv e-prints* (2013), 1306.2307

Netzer, H., et al., *The Ionized Gas and Nuclear Environment in NGC 3783. IV. Variability and Modeling of the 900 Kilosecond Chandra Spectrum*, ApJ **599**, 933 (2003), astro-ph/0309096

Różańska, A., et al., *The Origin of Emission and Absorption Features in Ton S180 Chandra Observations*, ApJ **600**, 96 (2004), astro-ph/0309430

Steenbrugge, K. C., Kaastra, J. S., de Vries, C. P., Edelson, R., *XMM-NEWTON High resolution spectroscopy of NGC 5548*, A&A **402**, 477 (2003), astro-ph/0302493

Steenbrugge, K. C., et al., *Simultaneous X-ray and UV spectroscopy of the Seyfert galaxy NGC 5548. II. Physical conditions in the X-ray absorber*, A&A **434**, 569 (2005), astro-ph/0501122

Stern, J., et al., *Radiation pressure confinement - III. The origin of the broad ionization distribution in AGN outflows*, MNRAS **445**, 3011 (2014), 1408.4940

Tombesi, F., et al., *Unification of X-ray winds in Seyfert galaxies: from ultra-fast outflows to warm absorbers*, MNRAS **430**, 1102 (2013), 1212.4851

Turner, A. K., Fabian, A. C., Lee, J. C., Vaughan, S., *The soft X-ray absorption lines of the Seyfert 1 galaxy MCG-6-30-15*, MNRAS **353**, 319 (2004), astro-ph/0405570

Winter, L. M., Mushotzky, R., *The Complex X-ray Spectrum of the Sefyert 1.5 Source NGC 6860*, ApJ **719**, 737 (2010), 1006.4523

Winter, L. M., Veilleux, S., McKernan, B., Kallman, T. R., *The Swift Burst Alert Telescope Detected Seyfert 1 Galaxies: X-Ray Broadband Properties and Warm Absorbers*, ApJ **745**, 107 (2012), 1112.0540

Yaqoob, T., et al., *The Kinematics and Physical Conditions of the Ionized Gas in Markarian 509. I. Chandra High Energy Grating Spectroscopy*, ApJ **582**, 105 (2003), astro-ph/0208530