Absorption Measure Distribution in AGN

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The most common feature of the X-ray outflows observed in active galactic nuclei (AGN) is their broad ionization distribution spanning up to ~ 5 orders of magnitude in ionization levels. This feature is quantified in terms of absorption measure distribution (AMD), defined as the distribution of column density with the ionization parameter. Recently, the photoionization models with constant pressure assumption are shown to well reproduce the observed shape of AMD. However, there exist inconsistencies in the normalization and the position of discontinuities presented in the AMD shape between the observation and model. In this work, we show that AMD normalization differs by one order of magnitude depending on the shape of ionizing spectral energy distribution (SED).

1 Absorption Measure Distribution

One of the major merit of high resolution X-ray spectroscopy was the discovery of highly ionized absorbing regions in the 50% of AGN commonly named warm absorbers (WA). The detection of X-ray blue shifted absorption lines from different ions of iron, has shown that the warm absorber is broadly stratified in ionization levels. The ionic column densities for the most abundant individual ions are obtained by fitting the observed high resolution X-ray lines. Those ionic column densities can be related to the total column density of the gas by adopting photoionization model.

Absorption measure distribution (AMD) in AGN outflows is defined as the distribution of matter column density with the ionization parameter along the line of sight, i.e., AMD $= dN_{\rm H}/d(\log \xi)$ (Holczer et al., 2007) where, $N_{\rm H}$ is the total column density and ξ is the ionization parameter. For the detail procedure of derivation of AMD from observations, we refer the reader to the paper by Holczer et al. (2007), but we would like to point out that any step of analysis always requires the high resolution X-ray data. Therefore, up to now we know only 7 objects with AMD determined from observations (Behar, 2009; Detmers et al., 2011; Stern et al., 2014).

Observations indicated that in all studied Seyfert's galaxies, derived AMDs span up to 5 orders of magnitude in ξ with the same normalization located at the level of $N_{\rm H} \sim 10^{22}$ cm^{-2} or slightly below (Behar, 2009; Stern et al., 2014). Furthermore, all observed AMDs have shown one prominent discontinuity between log$\xi \sim 0.5$ and 1.5 (Stern et al., 2014; Laha et al., 2014). However, in case of Mrk 509, Detmers et al. (2011) have shown that the AMD contains two strong discontinuities around the ionization degree of: $\log \xi \sim$ 2-3 and 3-4. The common interpretation of these discontinuities is the presence of thermally unstable zones in the outflow, which was proved in case of Mrk 509 with the use of photoionization calculations (Adhikari et al., 2015). The authors have shown that two unstable zones are clearly present in the computed models and their position agrees with the observed AMD in Mrk 509. Nevertheless, the normalization of the best fitted AMD model was one order of magnitude higher than the unique value obtained for all objects.

In this paper, we show that the shape of the ionized spectral energy distribution (SED) changes the AMD normalization by one order of magnitude. We have investigated systematic studies how AMD shape depends on physical parameters of ionized gas. All photoionization calculations are done with the assumption that the gas clouds are under constant total pressure (Różańska et al., 2004, 2006; Stern et al., 2014; Adhikari et al., 2015; Goosmann et al., 2016). One of the most important consequence of the constant pressure models is self consistent stratification in the density and ionization across a single gas cloud. Stern et al. (2014) has shown that the observed AMD normalization can be well produced by radiation pressure confinement (RPC) model, i.e. constant pressure model in CLOUDY (Ferland et al., 2013) numerical code. Nevertheless, RPC model computed by CLOUDY does not explain prominent discontinuity present in the observed AMD. For our research we use photoionization code TITAN (Dumont et al., 2000), which can well reproduce observed discontinuities caused by thermal instability (Adhikari et al., 2015).

Among many computed models, in this paper we present two extreme cases of SEDs. Considered spectral shapes differ in the strength of optical/UV disk emission and the ratio of hard X-ray power law luminosity to the luminosity of an accretion disk. We show that AMD normalization agrees with the observed one, when illuminating SED displays strong disk component with luminosity 100 times larger than the X-ray power law luminosity.

2 Photoionization models

We compare here two SED shapes obtained by varying the mass accretion rates $\dot{m}$ and the ratio of disk luminosity to the X-ray power law luminosity $L_{\rm disk}/L_{\rm X}$. For the computations of the disk contribution to the SED, we took the multi-color black body emission from an accretion disk around black hole of the mass $M_{\rm BH} = 10^8$ $M_{\odot}$ with two values of accretion rate which differ by the factor of 100. Hard X-ray emission is assumed to be a power law with the photon index Γ chosen in the way to fulfill relative normalization required by us. The final SED shapes, named SED A and SED B are obtained by taking i) $\dot{m}$= 0.1 and $L_{\rm disk}/L_{\rm X}$= 100 and ii) $\dot{m}$= 0.001 and $L_{\rm disk}/L_{\rm X}$= 1 respectively. The resulting SED shapes are shown in Fig. 1 left panel.

We performed photoionization calculations using the numerical code TITAN assuming that ionized gas is in total pressure equilibrium i.e. $P_{\rm gas} + P_{\rm rad}$=const at each optical depth of the cloud. For the detailed properties of the TITAN code and its capability to solve the radiative transfer accounting for all appropriate physical processes, we refer the reader to the relevant literature (Collin et al., 2004; Gonçalves et al., 2006; Różańska et al., 2006). For the purpose of this paper we assumed plane parallel slab of gas and assigned the gas density at its surface to be 10^8 cm^{-3}, which increases in the inner layers due to the compression by incident radiation field. As the result, WA is strongly stratified, and the appropriate temperature gradients are presented in Fig. 1 right panel. Geometrically thick, hot layer is accompanied by the strong temperature gradient on the back side of the cloud, where ionization drops steeply. The resulting ionization front is geometrically very thin.

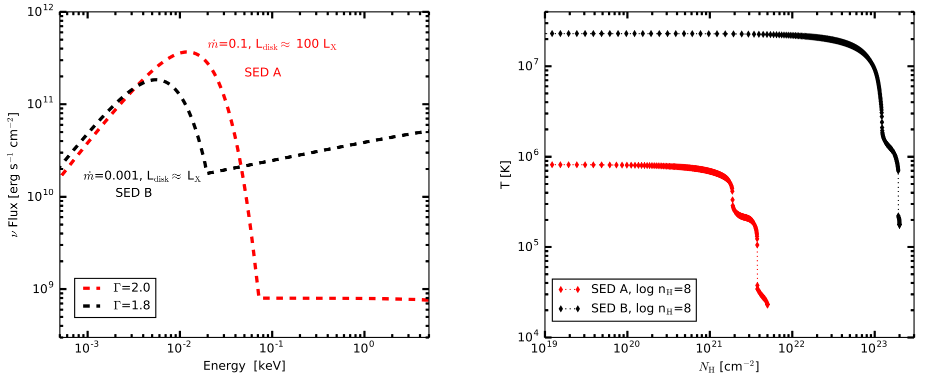

Fig. 1: Two SED shapes used in this paper are presented in left panel, while right panel represents temperature structure across WA for the gas illuminated by those SEDs.

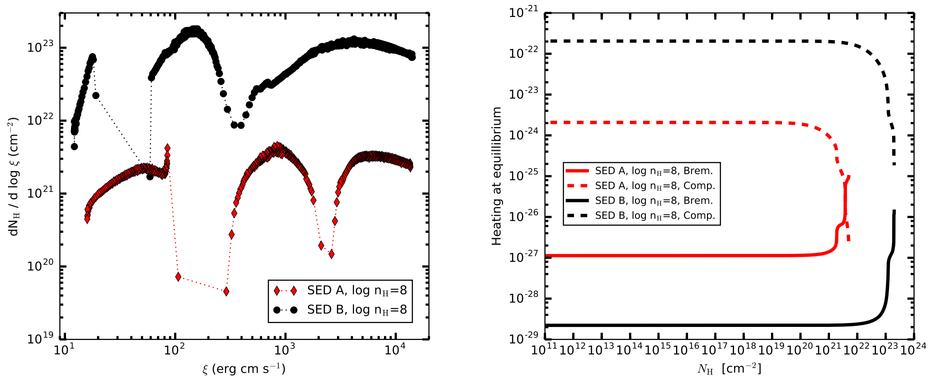

Fig. 2: AMD models for two spectral shapes: SED A (red) and SED B (black) for the gas density 10^8 cm^{-3} at the cloud surface (left panel). Right panel shows the amount of heating caused by Compton and Bremsstrahlung processes across both zones.

3 Results and discussion

The AMD models computed with TITAN photoionization code are shown in the right panel of Fig. 2. We found that the AMD models obtained for the SED B have higher normalization by the factor of $\sim$25 than the models for the SED A. These results show that the shape of the incident radiation changes the normalization of AMD models. Strong disk component with weak hard X-ray power law produces lower AMD normalization in agreement with observations. We have checked that our results do not depend much on the value of X-ray power law photon index Γ.

Adhikari et al. (2015) have found that the AMD structure depends on the gas density. We conclude here that the dependence of AMD on the SED and on the gas density is degenerated and complex. Final conclusion from our model computations for large parameters space is in progress and will be reported in the future paper. The next generation X-ray mission *ATHENA* with its high resolution instrument *X-IFU*, will be able to resolve more absorption lines with unprecedented details allowing for better understanding of AMD nature from observations.

Acknowledgements. This research was supported by Polish National Science Center grants No. 2015/17/B/ST9/03422, 2015/18/M/ST9/00541, and 2016/21/N/ST9/03311.

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