Reproducing the X-Ray Soft Step @ 0.9 keV Observed in the Spectrum of Ark 564 Using Reflection Models

José M. Ramírez and Snell Rojas

Abstract Using reliable atomic data, we attempt to reproduce the global 100 ks X-ray spectrum of the narrow-line Seyfert 1 Galaxy Ark 564, observed with the Low Energy Transmission Grating Spectrometer (LETGS) on board *Chandra*. In order to do this, we use accretion disk and reflection flow models.

1 Introduction

Narrow-line Seyfert 1 galaxies (NLS1s) are a subclass of the "normal" Seyfert 1 galaxies, which exhibit in their optical spectra H_β lines with full width at half maximum FWHM < 2000 km s^{-1}and strong Fe II emission (Osterbrock and Pogge 1985; Boroson and Green 1992). X-ray observations of these objects reveal extreme spectral and temporal properties, with Ark 564 being perhaps the more representative and the most observed Seyfert of this category. NLS1s show a "soft X-ray excess emission", which has been the subject of an intense debate for at least two decades. In particular, Pounds et al. (1995) proposed that this soft excess might be produced by an optically thick emission from the accretion disk. However, the temperature of this optically thick region ($kT \sim 0.1$–0.15 keV) is to high to support a disk around a supermassive black hole (SMBH).

On the other hand, the soft excess is well fitted with a blackbody, which has a roughly constant temperature of ~ 0.1–0.2 keV over a wide range of SBH masses (Gierliński and Done 2004). However, if it is thermal, this temperature could be explained by a slim disk in which the temperature is raised by photon trapping

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J. M. Ramírez (✉) · S. Rojas
Centro de Física, Instituto Venezolano de Investigaciones Científicas IVIC, Apartado Postal 20632, Caracas1020-A, Venezuela
e-mail: josem@ivic.gob.ve

S. Rojas
e-mail: snell0808@hotmail.com

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(Czerny et al. 2003; Gierliński and Done 2004; Crummy et al. 2006). A further explanation for the soft X-ray step is related to the atomic physics and considers that the detected X-ray emission could be dominated by reflection off the walls of ring-like structures formed by clumping of cold and dense material owing to instabilities of the accretion disk (Fabian et al. 2002).

2 Observation of Ark 564

After having properly extracted both the source and the background spectra from each arm of the dispersed spectrum as received by the arrange HRC + LETG (i.e., High Resolution Camera plus Low Energy Transmission Grating on board Chandra), we have merged them to increase the signal-to-noise ratio (S/N) of the final spectrum. The analysis presented here is entirely based on this merged spectrum. The effective areas (EA) for the dispersion orders 2–10 employed in the fitting procedures were built up using the standard CIAO task `mkgarf` and `fullgarf`. For the first order we used the corrected EA of Beuermann et al. (2006), while EA order 1–10 (positive and negative orders) were added together for use with the corresponding merged spectrum. A log of the observation is shown in Table 1.

Figure 1 shows the best-fit single power-law model to the data, where an emission excess is clearly seen. We note that this is qualitatively similar to the soft excess reported in Comastri et al. (2001); Vignali et al. (2004) and Papadakis et al. (2007). In order to investigate the nature of this soft excess (or soft step), which is still subject to debate (Done and Nayakshin 2007; Ramírez 2013), we also fit several other components to describe the soft band. The extra components are: the single blackbody model [`TBabs*(zpowerlw + bb)`] and the single accretion disk reflection model model [`TBabs*(zpowerlw + xillver)`] (García and Kallman 2010). All models account for the galactic absorption in the line-of-sight towards Ark 564, of $N_H = 6.4 \times 10^{20}\text{cm}^{-2}$, using the TBabs model included in xspec (Wilms et al. 2000).

Table 1 We merge the dispersion orders +1 and −1 to increase the signal-to-noise (S/N)

Log of the LETGS observation of Ark 564	
Telescope	Chandra
Instrument	HRC + LETG
Channel type	PHA
Source exposure time	199 ks

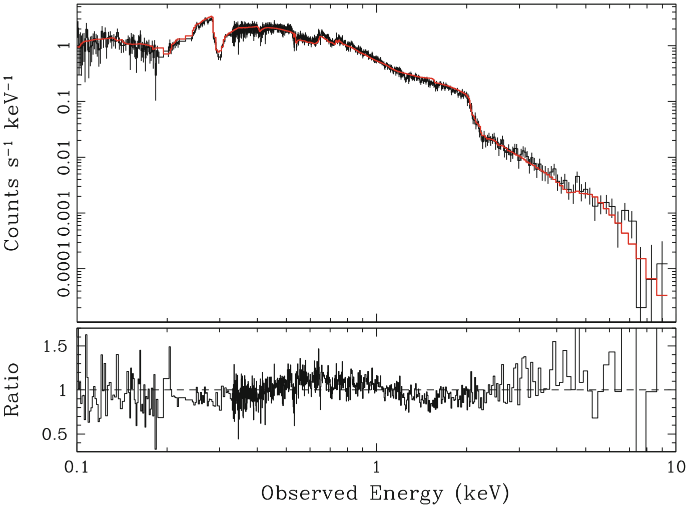

Fig. 1 Single absorbed power-law best-fit to the LETGS X-ray spectrum of Ark 564 (*points with error bars*). With this model we are able to observe significant residuals around 0.9 keV and at high energies (5–8 keV), which are believed to be an "excess" in emission

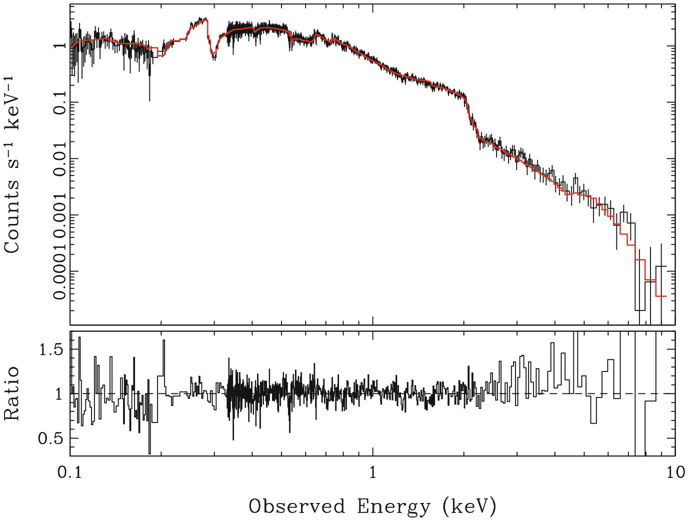

Fig. 2 The solid line is an absorbed power-law plus a black body model plotted over the LETGS X-ray spectrum of Ark 564 (*points with error bars*). There is only a slight improvement over the power-law. See the text for details

3 Results

We have measured in quantitative terms the quality of the fit using χ^2-statistics. This gives a measure of the quadratic deviation between the data and the model. In the case of the single power-law, we obtain $\chi^2/dof = 1.89$, where dof is the degree of freedom, defined as the number of data channels minus the number of parameters in the model. When a blackbody model is added to the absorbed power-law, in an attempt to characterize the residual at soft energies (∼0.9 keV), the power-law fit improves only slightly with $\chi^2/dof = 1.87$. The results are shown in Fig. 2.

Given that the temperature of the optically thick region ($kT \sim 0.1$–0.15 keV) is to high for supporting a disk around a SMBH, it is necessary to use a more sophisticated model. Accretion disks around SMBHs reflect the emission from the central region, re-processing high-energy photons, and producing emission and absorption features. These features form complexes, which actually improve the description of the data around 0.9 keV, with $\chi^2/d_{of} = 1.86$. Tables 2 and 3 show a comparison between `TBabs*zpowerlw`, `TBabs*(zpowerlw + bb)`, and `TBabs*(zpowerlw + xillver)` with their respective parameter values. Figure 3 shows the best-fit physical model, where the solid line was obtained using the partially ionized accretion disk model `TBabs*(zpowerlw + xillver)`.

Table 2 Parameter values of the model TBabs*zpowerlw

Model: TBabs*zpowerlw			
Component	Parameter	Unit	Value
TBabs	nH	10^{22}	0.064
powerlaw	PhoIndex		2.886
powerlaw	norm		0.012

Table 3 Parameter values of the models `TBabs*(zpowerlw + bb)` and `TBabs*(zpowerlw + xillver)`

Model: TBabs*(zpowerlw + bb)				TBabs*(zpowerlw + xillver)			
Component	Parameter	Unit	Value	Component	Parameter	Unit	Value
TBabs	nH	10^{22}	0.064	TBabs	nH	10^{22}	0.064
powerlaw	PhoIndex		2.894	zpowerlw	PhoIndex		2.861
powerlaw	norm		0.0121	zpowerlw	Redshift		0.024
bbody	kT	keV	0.137	zpowerlw	norm		0.088
bbody	norm		2.804×10^{-4}				
				xillver	log(xi)		1.931
				xillver	Fe/solar		1.000
				xillver	Redshift		0.024

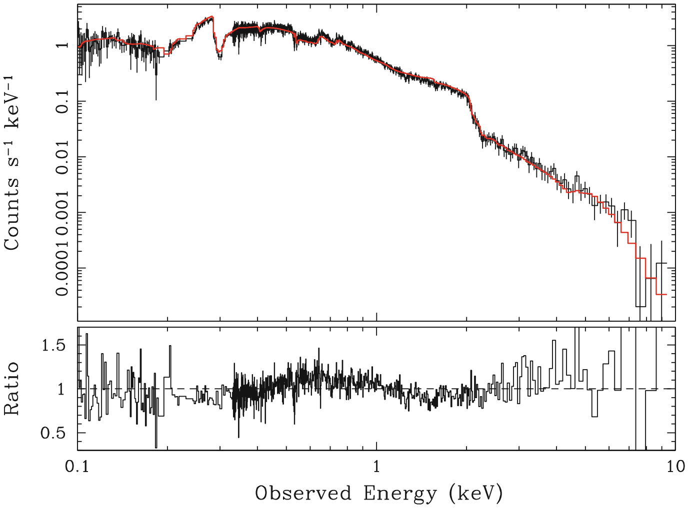

Fig. 3 The solid line is an absorbed `TBabs*(zpowerlw + xillver)` model (García and Kallman 2010), plotted over the LETGS X-ray spectrum of Ark 564 (*points with error bars*). This is the best-fit physical model. See the text for details

4 Conclusions

The main conclusions from this work are:

- We have studied in detail the global (0.1–10 keV) LETGS spectrum of Ark 564. Reproducing this spectrum will certainly require more sophisticated and complex models than just semi-empirical models, like the power-law plus blackbody model, or put-by-hands absorption edges (Matsumoto et al. 2004; Ramírez et al. 2008; Ramírez 2013).
- The best-global-fit in this work corresponded to the partially ionized accretion disk model `Tbabs*(zpowerlw + xillver)` (García and Kallman 2010), which uses a self-consistent photoionization model with reliable atomic data. This fit includes a more comprehensive set of absorption and emission lines than it has previously been tried for this kind of object.
- Future work must focus on the use of more complex models, which combined with high-resolution/quality observations are expected to improve the statistics.

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References

Beuermann K, Burwitz V, Rauch T (2006) Establishing HZ43 A, Sirius B, and RXJ185635-3754 as soft X-ray standards: a cross-calibration between Chandra LETG + HRC-S, the EUVE spectrometer, and the ROSAT PSPC. Astron Astrophys 458:541–552

Boroson TA, Green RF (1992) The emission-line properties of low-redshift quasi-stellar objects. Astrophys J Suppl Ser 80:109–135

Comastri A, Stirpe GM, Vignali C, Brandt WN, Leighly KM, et al. (2001) BeppoSAX observations of narrow-line Seyfert 1 galaxies. II. Ionized iron features in Arakelian 564. Astron Astrophys 365:400–408

Crummy J, Fabian AC, Gallo L, Ross RR (2006) An explanation for the soft X-ray excess in active galactic nuclei. Mon Not R Astron Soc 365:1067–1081

Czerny B, Nikołajuk M, Różańska A, Dumont A-M, Loska Z, Zycki PT (2003) Universal spectral shape of high accretion rate AGN. Astron Astrophys 412:317–329

Done C, Nayakshin S (2007) Can the soft excess in AGN originate from disc reflection? Mon Not R Astron Soc 377:L59–L63

Fabian AC, Ballantyne DR, Merloni A, Vaughan S, Iwasawa K, Boller T (2002) How the X-ray spectrum of a narrow-line Seyfert 1 galaxy may be reflection-dominated. Mon Not R Astron Soc 331:L35–L39

García J, Kallman TR (2010) X-ray reflected spectra from accretion disk models. I. Constant density atmospheres. Astrophys J 718:695–706

Gierliński M, Done C (2004) Is the soft excess in active galactic nuclei real? Mon Not R Astron Soc 349:L7–L11

Matsumoto C, Leighly KM, Marshall HL (2004) A Chandra HETGS observation of the narrow-line Seyfert 1 galaxy Arakelian 564. Astrophys J 603:456–462

Osterbrock DE, Pogge RW (1985) The spectrum of narrow-line Seyfert 1 galaxies. Astrophys J 297:166–176

Papadakis IE, Brinkmann W, Page MJ, McHardy I, Uttley P (2007) XMM-Newton observation of the NLS1 galaxy Ark 564. I. Spectral analysis of the time-average spectrum. Astron Astrophys 461:931–942

Pounds KA, Done C, Osborne JP (1995) RE 1034 + 39: a high-state Seyfert galaxy? Mon Not R Astron Soc 277:L5–L10

Ramírez JM, Komossa S, Burwitz V, Mathur S (2008) Chandra LETGS spectroscopy of the quasar MR 2251–178 and its warm absorber. Astrophys J 681:965–981

Ramírez JM (2013) Chandra LETGS observation of the variable NLS1 galaxy Ark 564. Astron Astrophys 551:A95

Vignali C, Brandt WN, Boller T, Fabian AC, Aughan VS (2004) Arakelian 564: an XMM-Newton view. Mon Not R Astron Soc 347:854–860

Wilms J, Allen A, McCray R (2000) On the absorption of X-rays in the interstellar medium. Astrophys J 542:914–924