

X-ray Emission and Absorption Properties of Low-Mass Seyfert Galaxies

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Introduction

With the advent of large surveys such as SDSS, we can now systematically search for galaxies with small stellar velocity dispersions harboring AGN with estimated black hole masses below $10^6 M_{\odot}$ (Greene & Ho 2007, Barth et al. 2008). This allows us to begin to investigate any differences between the populations of low-mass AGN and their more massive counterparts. According to the unified model (Antonucci & Miller 1985), observational differences between type 1 and type 2 AGN are simply due to the orientation of the obscuring material surrounding the AGN, but there have been a few suggestions of “true” type 2 objects lacking broad line regions (BLR, see Ghosh et al. 2007, Gliozzi et al. 2007, Bianchi et al. 2008). We aim to investigate the absorption properties of low-mass Seyfert 2 galaxies to determine if the lack of broad line emission in these objects is due to obscuration as suggested by the unified model.

Sample Selection

♦ We select the four objects with the lowest stellar velocity dispersions ($\sigma_{\star} < 45$ km/s) from the low-mass Seyfert 2 sample of Barth et al. (2008, hereafter known as BGH08) for X-ray observations with the EPIC-pn instrument onboard XMM-Newton.

♦ Assuming these low velocity dispersions correspond to low-mass black holes, these objects would be the type 2 counterparts of the sample of type 1 objects found by Greene & Ho (2004, 2007).

♦ Each object was observed for ~ 25 ks. All data were reduced and analyzed with the standard pipeline processing, using SAS (v. 7.1.0) and XSPEC (v. 12.4.0aa).

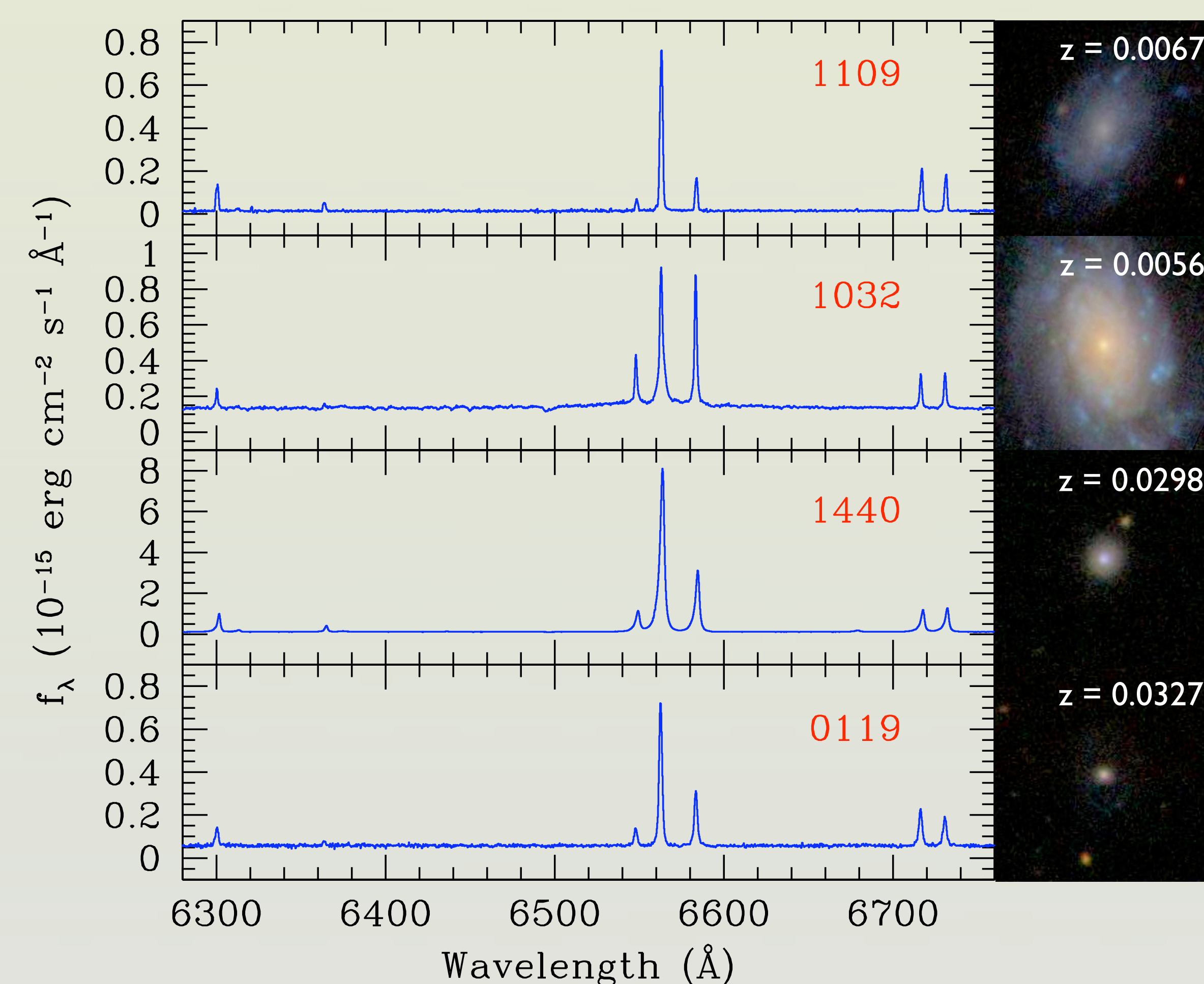


Figure 1: Keck ESI spectra covering the wavelength range from [O I] to the [S II] doublet. SDSS J1032 has very weak broad H α emission and SDSS J1440 shows possible weak broad H α emission (BGH08). The other two objects show no evidence for broad H α emission. Corresponding images are color-composites from SDSS and are 1" on each side.

SDSS J110912.40+612346.7

♦ Also known as UCG 06192 or MCG +10-16-069, this galaxy is a type 2 counterpart of the nearby dwarf Seyfert 1 galaxy NGC 4395, with similar host galaxy morphology and narrow emission lines, but no detectable broad line emission.

♦ The encircled energy profile falls below the instrumental PSF, suggesting possible extended emission from X-ray binaries (Figure 2).

♦ We calculate a hardness ratio, $HR = (C_H - C_S)/(C_H + C_S)$, where C_H is the hard count rate from 2 - 10 keV and C_S is the soft count rate from 0.5 - 2 keV (Table 1).

♦ Using the method of Gallagher et al. (2005), we calculate the photon index, Γ_{HR} , assuming the spectrum is well-fit by a simple power law with Galactic absorption (Table 1).

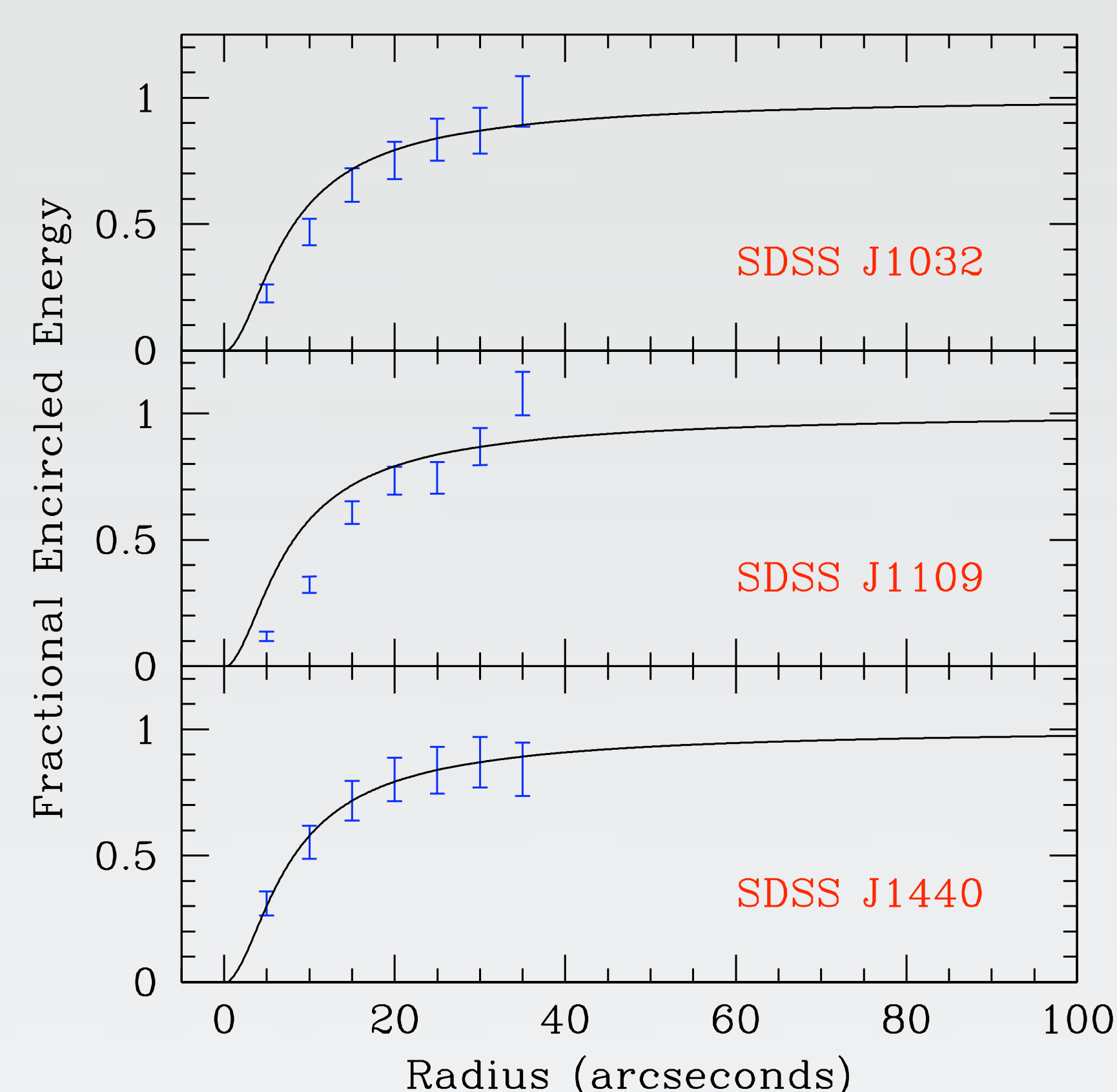


Figure 2: Fraction of encircled energy as a function of radius. The solid line shows the encircled energy curve of the XMM-Newton PSF. The data points are normalized such that 87% of the total energy is encircled at a radius of $R = 30''$.

Table 1: Summary of Sample Properties

Object	Counts (s^{-1})	HR	Γ_{HR}	L_X ($ergs s^{-1}$)	N_H (cm^{-2})
SDSS J011905.1+003745.0	< 6.6	$< 1.3 \times 10^{40}$	$> 1.5 \times 10^{22}$
SDSS J103224.9+650227.9	140.8	0.01 ± 0.06	1.1 ± 0.1	$(2.5 \pm 0.5) \times 10^{39}$...
SDSS J110912.4+612346.7	26.7	-0.13 ± 0.16	1.4 ± 0.2	$(4.6 \pm 2.5) \times 10^{38}$	8.8×10^{21}
SDSS J144012.7+024743.5	163.2	-0.43 ± 0.05	1.8 ± 0.1	$(3.4 \pm 0.9) \times 10^{40}$	2.3×10^{22}

SDSS J103234.85+650227.9

♦ Also known as NGC 3259, BGH08 previously detected weak broad H α emission.

♦ Spectral fitting was only possible below 5 keV, above which the source spectrum became indistinguishable from that of the background spectrum.

♦ Models consisting of a simple absorbed power law and an absorbed power law with a disk blackbody both produced strong residuals (Figure 3).

♦ The best fit was obtained with a more complex model consisting of an absorbed power law (set at $\Gamma = 1.1$) and a $kT = 0.2$ keV disk blackbody with a partial covering absorbed ($N_H = 4.3 \times 10^{22} cm^{-2}$) with a 95% covering fraction (Figure 2).

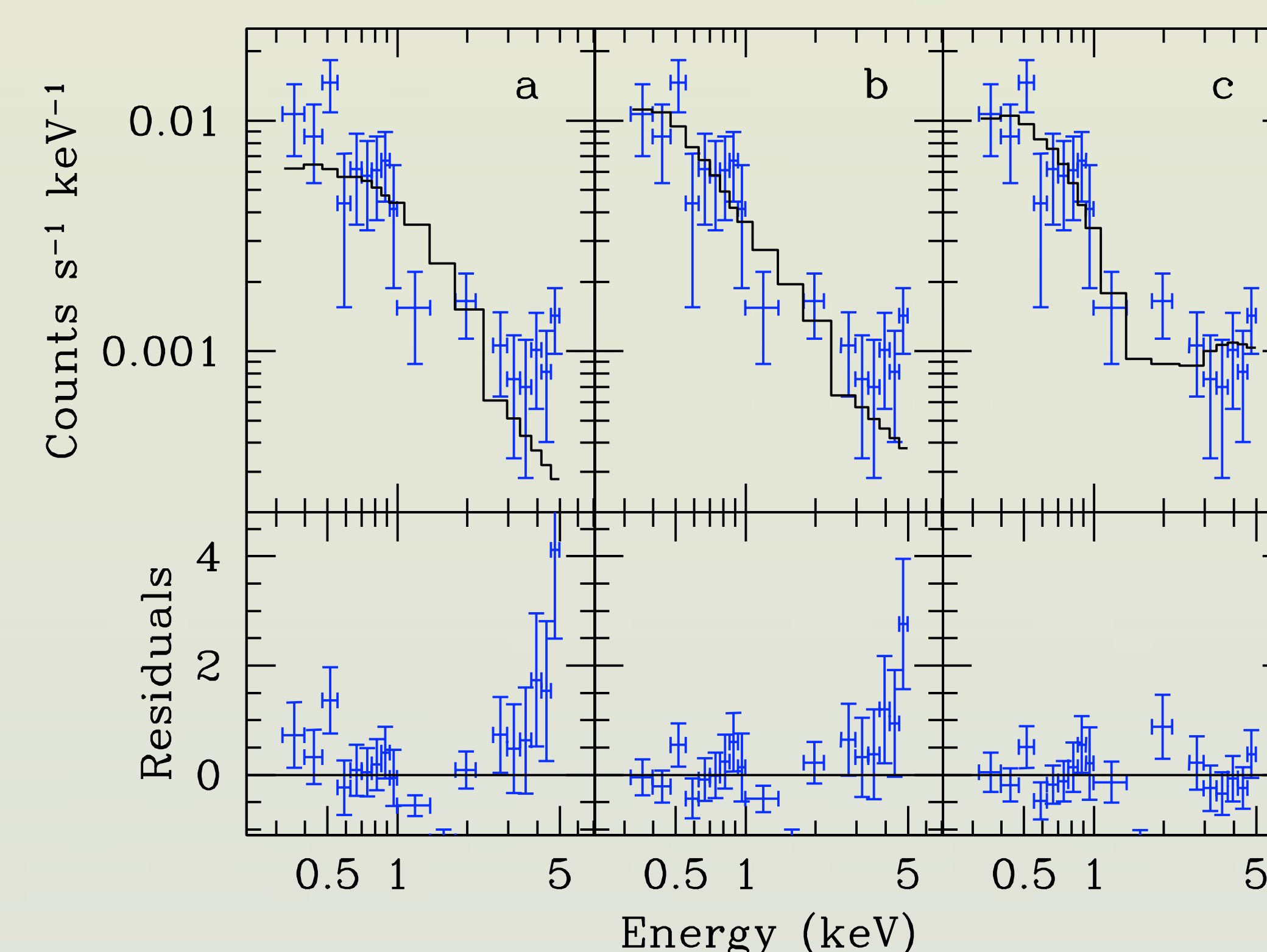


Figure 3: The spectrum of SDSS J1032 from 0.3 - 5.0 keV modeled (black line) with (a) an absorbed power law with absorption set at the Galactic value, (b) an absorbed (Galactic value) power law (photon index set to $\Gamma = 1.1$) with a thermal disk blackbody, and (c) an absorbed (Galactic value) power law ($\Gamma = 1.1$) with a thermal disk blackbody and a partial covering absorption component. Residuals are calculated as $Residual = (Data - Model)/Model$.

SDSS J144012.70+024743.5

♦ Also known as Tol 1437+030, this object has an optical spectrum similar to that of NGC 4395 and POX 52, but with only possible weak broad H α emission (BGH08).

♦ Spectral fitting was only possible below 1 keV, for the same reasons discussed for SDSS J1032.

♦ A simple absorbed power law showed strong residuals at $E < 0.6$ keV (Figure 4).

♦ The best fit was obtained by adding a thermal component (Raymond-Smith or MEKAL plasma) to the absorbed power law. The best fit had $\Gamma = 1.5$ and a $kT = 0.13$ keV plasma temperature with Galactic absorption (Figure 2).

♦ The fits with the Raymond-Smith plasma were indistinguishable from those with the MEKAL plasma, with the exception of an extra free parameter.

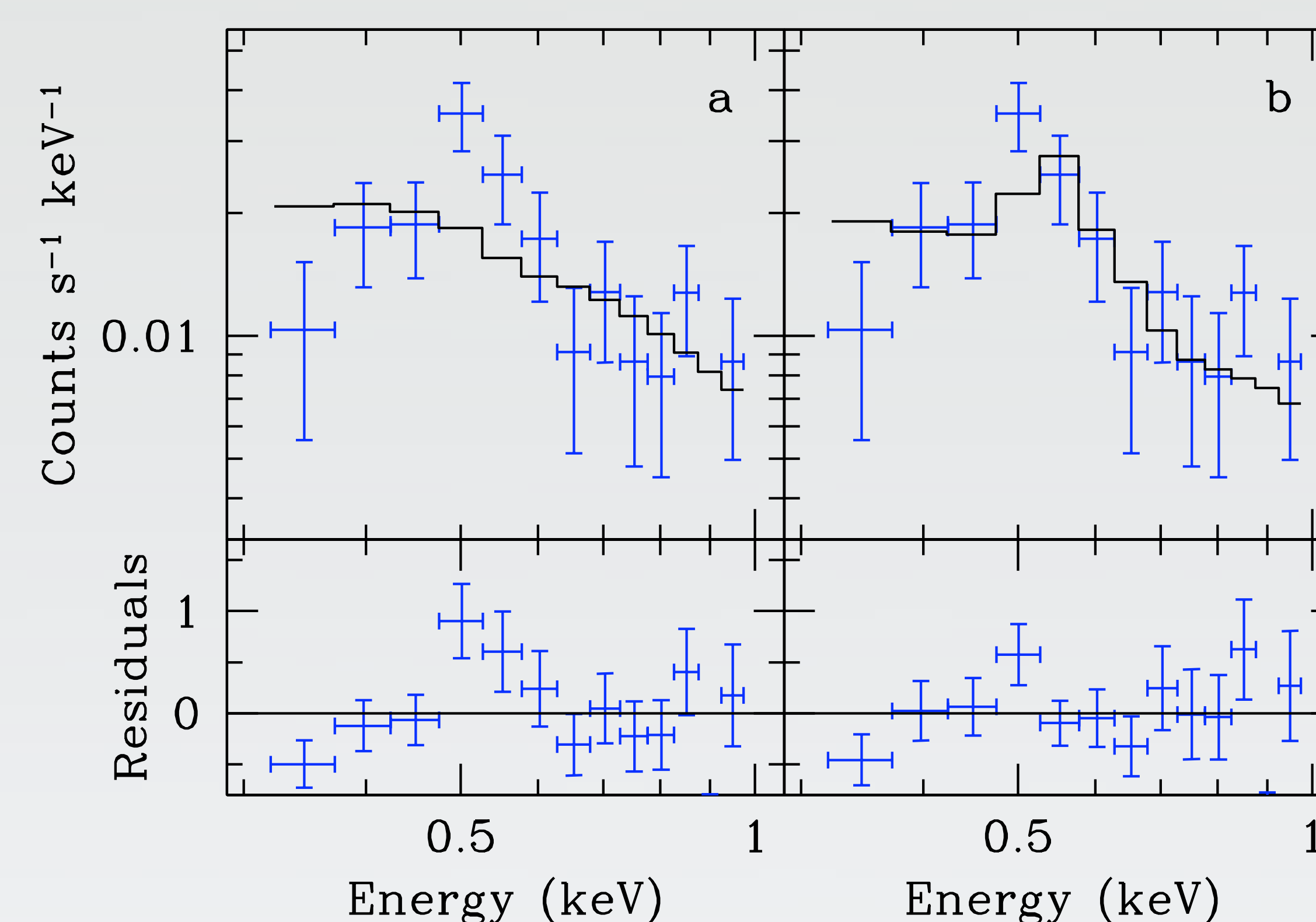


Figure 4: The spectrum of SDSS J1440 from 0.3 - 1.0 keV modeled (black line) with (a) an absorbed (set at the Galactic value) power law, and (b) an absorbed (Galactic value) power law with a Raymond-Smith plasma. Residuals are calculated as $Residual = (Data - Model)/Model$.

L_X-L_[O III] Correlation

♦ We use the relationship between the luminosity of the [O III] emission line and the unabsorbed 2 - 10 keV luminosity in order to estimate the absorption in each object.

♦ This relationship has been investigated to be intact for a range of objects, including both type 1 and 2 Seyferts and quasars (Kraemer et al. 2004, Heckman et al. 2005, Panessa et al. 2006).

♦ We use the correlation derived by Panessa et al. (2006) and plot the $L_{[O III]}$ measurements from SDSS spectra (BGH08) along with the observed L_X measured in this work in Figure 5.

♦ Comparing the L_X values calculated from the $L_{[O III]}$ values to the L_X values measured from the XMM-Newton data, we can attempt to quantify the level of intrinsic absorption within the 3 objects that fall below the correlation.

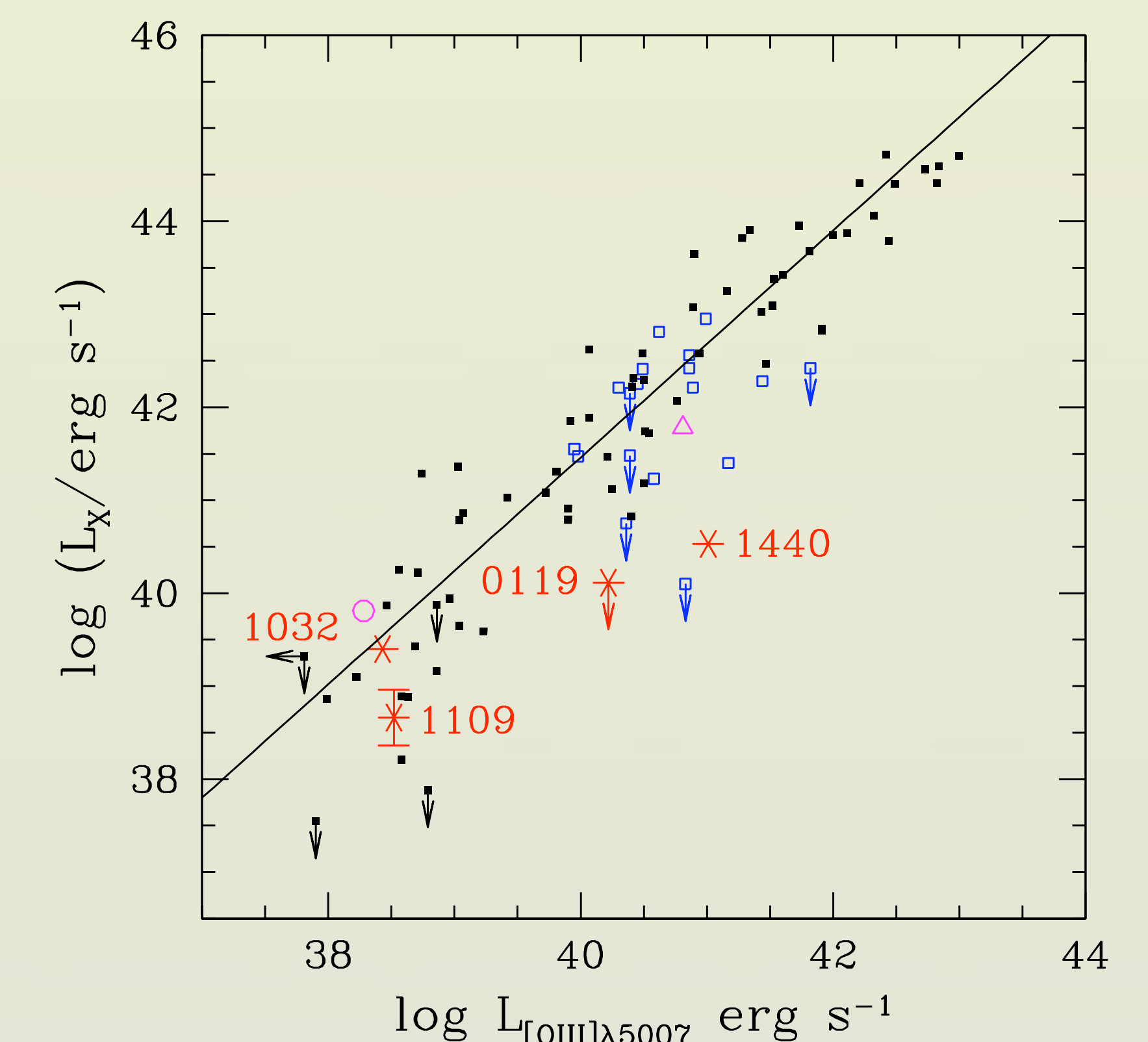


Figure 5: Plot of $L_{[O III]}$ vs $L_{2-10 keV}$ with our sample (red asterisks) along with the objects (black, filled squares) from Panessa et al. (2006), which includes quasars and Seyfert 1 and 2 galaxies, all corrected for X-ray absorption except for our sample. The open symbols represent NGC 4395 (magenta circle; Panessa et al. 2006), POX 52 (magenta triangle; Barth et al. 2004, Thornton et al. 2008) and intermediate mass Seyfert 1 objects (blue squares; Greene & Ho 2004, Desroches et al. 2009). The solid line represents the least-squares fit derived by Panessa et al. (2006).

Conclusions

♦ SDSS J1109 is an object of particular interest, not only for the strong similarity between it and NGC 4395, but also because it has the lowest X-ray luminosity in the sample. There are three possible scenarios that could explain our observations.

1. The radial profile shows possible evidence for extended emission and with $L_X \sim 5 \times 10^{38} ergs s^{-1}$ this could be due to a few X-ray binaries. If this is the case, then the central source must be more heavily absorbed than the $N_H \sim 10^{22} cm^{-2}$ estimated based on the observed L_X .

2. The observed X-ray emission is from the central engine and an absorbing column density of $N_H \sim 10^{22} cm^{-2}$ is enough to obscure any emission from the BLR in this particular object.

3. There is no strong evidence for absorption based on its location in the $L_{[O III]}$ - L_X plane and therefore we should be able to observe BLR emission from the central engine. Since no BLR emission has been detected in high resolution spectra, this would mean SDSS J1109 is lacking a BLR and is a candidate “true” type 2 Seyfert galaxy.

♦ High signal-to-noise X-ray observations are needed to further investigate and hopefully, quantify the absorption properties of these objects. Mid-infrared spectra are another important tool used to investigate absorption and reprocessing of the AGN continuum. We plan on continuing to investigate both low-mass Seyfert 1 and 2 objects using Spitzer IRS spectra in a future paper.

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