The soft X-ray spectrum and high velocity outflow in BLRG 3C445.

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1. Introduction

3C 445 (z ~ 0.0562) is a moderately luminous (L_{bol} ~ 2x10^{45} erg s^{-1}) radio-loud source optically classified as a broad line radio galaxy (BLRG). Previous XMM-Newton observations by Sambruna et al. (2007) and Grandi et al. (2007) independently found that, at odds with its classification as a Type-1 AGN, 3C 445 exhibits an absorbed X-ray continuum and a line dominated soft X-ray spectrum. These emission lines were attributed to circumnuclear gas photoionized by the central engine; thus making 3C 445 the first radio-loud source to have a confirmed circumnuclear warm absorber/emitter.

Here we present a summary of the main results obtained from broad-band (0.5-150 keV) spectral analysis of 3C 445. Our study comprises of both a deep 200ks observation with the Chandra Low Energy Transmission Grating (LETG) obtained between 25 September - 3 October 2009 and archival (2007) Suzaku / Swift spectra. Despite the disparity in the date of observation there is no significant variability observed in the source.

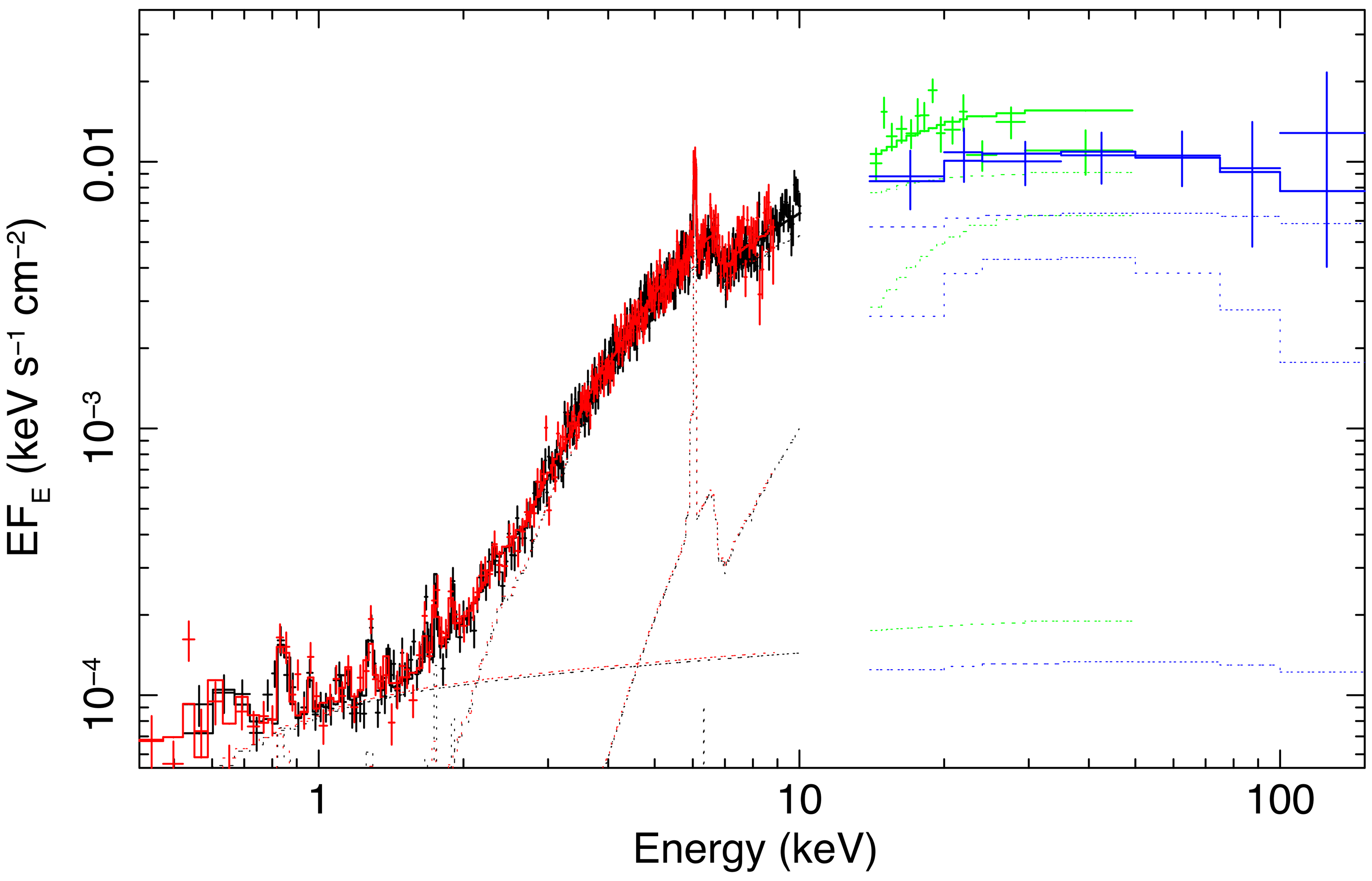

Figure 1:- Best-fit continuum and model for the *Suzaku* (XIS: red & black; PIN: green) and *Swift* (BAT: blue) data. (The spectrum is clearly heavily absorbed towards lower energies as would be expected for a Type-2 source.)

2. Chandra LETG analysis

➡ The 0.5-9.0 keV continuum is best modelled with a primary power-law continuum (Γ = 1.73$^{+0.22}_{-0.19}$) absorbed by a single highly significant (>99.9%) absorber with column density N_H = (1.85$^{+0.09}_{-0.11}$)x10^{23} cm^{-2}, and ionization parameter logξ ~ 1.42$^{+0.20}_{-0.12}$ erg cm s^{-1}. The absorber appears to be outflowing with a velocity of 0.034±0.002c (v ~ 10,200±600 km s^{-1}). An additional scattered power-law with Γ tied to the primary is needed to fit the soft-excess below 2 keV.

➡ The plethora of emission lines revealed below 2.0 keV (Fig. 2) are mainly consistent with H- and He-like species of O to Si while the emission lines at ~2.34 keV and ~6.36 keV are consistent with fluorescence transitions from neutral S Kα and Fe Kα, respectively. All line detections are consistent with their laboratory rest-frame energies and thus do not appear to have an origin in outflowing gas. The emission region is accurately described with XSTAR (Kallman & Bautista, 2004) by the addition of two photoionized media with ionization parameter logξ = 1.8$^{+0.1}_{-0.3}$ erg cm s^{-1} and logξ = 3.0±0.4 respectively.

➡ The velocity widths of OVII, OVIII, S Kα and Fe Kα are resolved and indicate a distance of r ~ 0.01-0.2 pc from the ionizing source suggesting an origin in the broad line region (BLR). The ratio of the OVII forbidden and intercombination lines corresponds to densities of n_e > 10^{10} cm^{-3}, independently corroborating a BLR origin. Also, the resolved thermal widths of the OVII and OVIII RRCs (k_BT ~ 3 eV) strongly prefer photo- to collisional-ionization as would be expected from BLR gas.

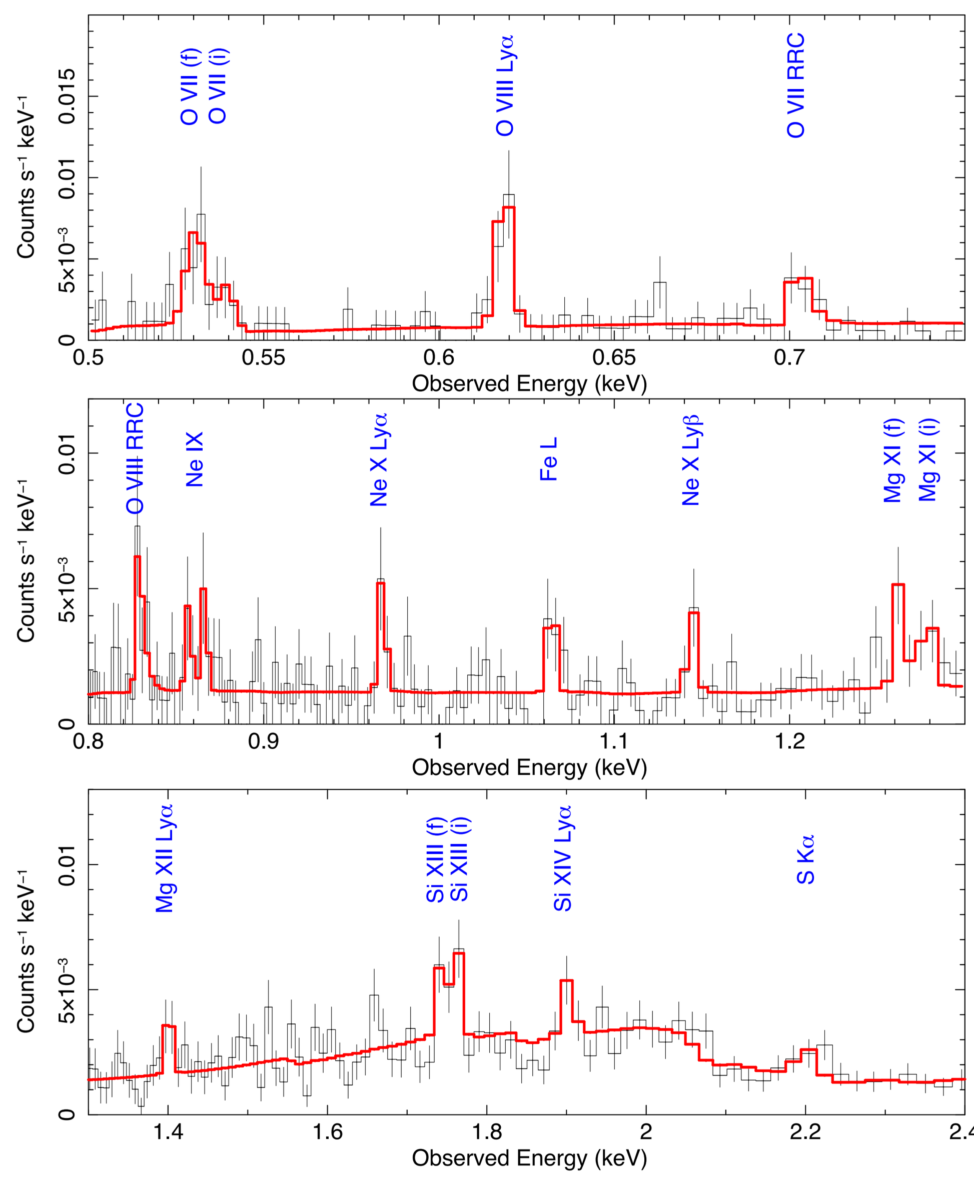

Figure 2:- *Chandra* LETG spectrum of 3C445 showing emission lines from O, N, Mg, Si, Fe L, S Kα. Spectrum binned to the resolution of the LETG FWHM.

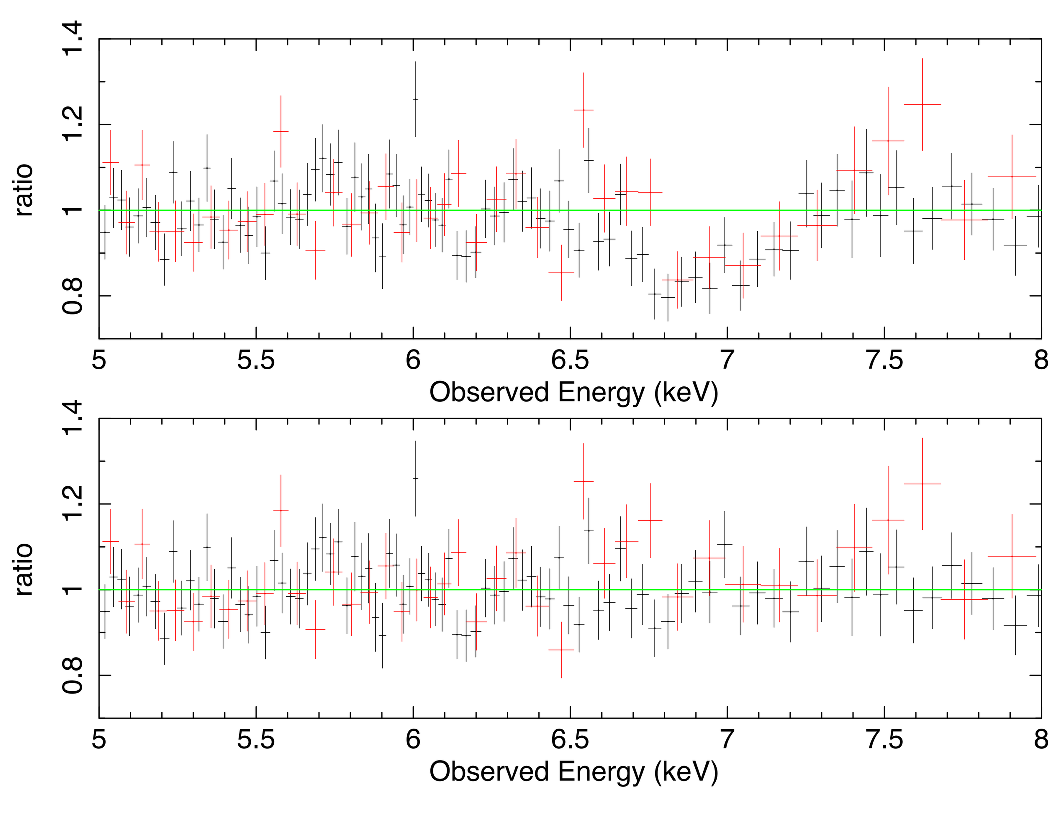

Figure 3:- *Top*: residuals of a fit in the Fe K region of the XIS-FI and XIS1 data with the best-fit model obtained from the *Chandra* data. *Bottom*: residuals for the same model, but with a broad Gaussian absorption line added at 7.298±0.049 keV.

3. Suzaku & Swift analysis

➡ Applying the best-fit Chandra LETG XSTAR model to the Suzaku/Swift data unveils a substantial broad (σ = 160$^{+63}_{-51}$ eV) absorption feature at 7.298±0.050 keV (observed) as shown in Fig. 3 (top panel). This feature is best modelled as being due to K-shell resonance transitions of Fe XXV and/or Fe XXVI which is outflowing at ~0.05c (~15,000 km s^{-1}). The alternative modelling of this feature as being due to the Fe K absorption edge (expected at 7.1 keV) provides a significantly worse fit ($\Delta\chi^2$ = +47.2).

➡ Analogous modelling of the absorption feature with XSTAR requires the addition of a second absorbing column of N_H = (5.27$^{+2.84}_{-0.27}$)x10^{22} cm^{-2} and logξ ~ 4 erg cm s^{-1}, with intrinsic velocity broadening of V_{turb} = ~10,000 km s^{-1}. Consistent with the earlier identification with blue-shifted Fe XXV and/or Fe XXVI the XSTAR absorber is also found to be outflowing at ~0.05c. Our resultant best-fit Suzaku/Swift model is shown in Fig. 1.

4. Conclusion & Discussion

➡ Our Chandra analysis further elucidates the prior detection of an underlying Sy2-like soft X-ray emission line spectrum in the optically classified BLRG 3C 445. The emission is excellently constrained in the LETG data (Fig. 2) and modelling with XSTAR requires both a highly and lowly ionized region of emitting gas. The emission is likely associated with the photoionized BLR and has velocity widths in the range from 2000-8000 km s^{-1} (FWHM).

➡ Wide-band absorption modelling requires both a region of lowly ionized (best constrained with the LETG) and a region of highly ionized (best constrained with Suzaku/Swift) absorbing gas. Both regions are consistent with a column density of N_H ~ 10^{23} cm^{-2} as suggested in previous observations and both appear to be located ~0.01pc of the central engine. Detailed discussion regarding probable geometries for these absorbers is to be discussed in Reeves et al. (2010; in prep) and Braito et al. (2010; in prep).

➡ We find the highly ionized absorber to be the most profuse source of matter outflow in 3C 445 with a mass outflow rate of ~1M_{sun} yr^{-1}. This equates to a kinetic flux of ~10^{43} erg s^{-1} which, assuming a typical AGN life-time of 10^8 years, yields to a total lifetime energy output of E_{out} ~ 10^{59} erg. This is comparable to the typical binding energy of a 10^{11} M_{sun} galaxy bulge and thus suggests that the energy imparted by the AGN may have had a significant effect on the evolution of 3C 445.

References

Sambruna, R. M., Reeves, J. N., & Braito, V. 2007, ApJ, 665, 1030
Grandi, P., Guainazzi, M., Cappi, M., & Ponti, G., 2007, MNRAS, 381, 21
Kallman, T., & Bautista, M., 2001, ApJS, 133, 221

Forthcoming Literature

Detailed Chandra LETG analysis: ***Reeves et al. (2010; in prep)***
Broad-band Suzaku & Swift analysis: ***Braito et al. (2010; in prep)***