# *Suzaku* Observations of the Radio Galaxy 3C 33

Daniel A. Evans[1], James N. Reeves[2], Martin J. Hardcastle[3],
Ralph P. Kraft[4], Julia C. Lee[4], and Shanil N. Virani[5]

[1] MIT Kavli Institute for Astrophysics and Space Research, 77 Massachusetts Avenue, Cambridge, MA 02139, USA
[2] Astrophysics Group, School of Physical and Geographical Sciences, Keele University, Keele, ST5 5BG, UK
[3] School of Physics, Astronomy & Mathematics, University of Hertfordshire, College Lane, Hatfield AL10 9AB, UK
[4] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
[5] Department of Astronomy, Yale University, P.O. Box 208101, New Haven, CT 06520, USA
*E-mail (DE): devans@space.mit.edu*

Abstract

We present results from a new 100-ks *Suzaku* observation of the nearby radio galaxy 3C 33, and investigate the nature of absorption, reflection, and jet production in this source. We model the 2–70 keV nuclear continuum with a power law that is absorbed either through one or more layers of pc-scale neutral material, or through a modestly ionized pc-scale obscurer. The expected signatures of reflection from a neutral accretion disk are absent in 3C 33: there is no evidence of a relativistically blurred Fe K$\alpha$ emission line, and no Compton reflection hump above 10 keV. We discuss the implications of this for the nature of jet production in 3C 33.

Key words: workshop: proceedings – galaxies: active – galaxies: jets – galaxies: individual (3C 33) – X-rays: galaxies

## 1. Overview

The origin of jets in active galactic nuclei (AGN) is one of the most important unsolved problems in extragalactic astrophysics. While 90% of all AGN (Seyfert galaxies and radio-quiet quasars) show little or no jet emission, the remaining 10% (the radio-loud AGN and radio-loud quasars) launch powerful, relativistic twin jets of particles from their cores. Since jets transport a significant fraction of the mass-energy liberated during the accretion process, sometimes out to ∼Mpc distances, understanding how they are produced is key to a complete picture of accretion and feedback in AGN.

X-ray observations of the nuclei of radio-loud and radio-quiet AGN are essential for establishing the connection between the accretion flow and jet. Continuum X-ray observations of radio-loud AGN have mostly been restricted to bright broad-line radio galaxies (BLRGs) and quasars, which are oriented relatively close to the line of sight with respect to the observer. In these sources, unabsorbed non-thermal emission from the jet could potentially contaminate the unabsorbed accretion-related X-ray spectrum and thus dilute the apparent strength of the Compton reflection component. *Narrow*-line radio galaxies (NLRGs), such as 3C 33, on the other hand, which are oriented at low to intermediate angles, have the distinct advantage that (unabsorbed) jet-related X-ray emission can be readily spectrally separated from (heavily absorbed) accretion-related emission, allowing a direct measurement of the strength of Compton reflection. However, narrow-line radio galaxies tend to be relatively faint X-ray sources compared to broad-line objects.

Here, we present the results from a 100-ks *Suzaku* observation of one of the brightest NLRGs, 3C 33, the only such source known so far to show potential evidence for Compton reflection in its 2–10 keV X-ray spectrum. Previous observations of 3C 33 with *Chandra* and *XMM-Newton* (Kraft et al. 2007) showed that its continuum spectrum could not be adequately modeled by the combination of a heavily obscured power law and a soft power law normally fitted to narrow-line FRII sources, due to the large residuals present between 2–4 keV. We use our *Suzaku* observation to investigate Compton reflection in this radio galaxy.

## 2. Suzaku Spectral Analysis

We restricted the energy range for our spectral fits to 2–10 keV (XIS) and 15–70 keV (PIN). We fitted to 3C 33 our canonical model for the X-ray spectrum of NLRGs: the combination of a heavily absorbed power law (likely to be associated with the accretion flow) and a soft, unabsorbed power law (Evans et al. 2006). This model gave a relatively poor fit to the spectrum: $\chi^2 = 150$ for 116 dof, with clear residuals at ∼3 keV. The photon in-

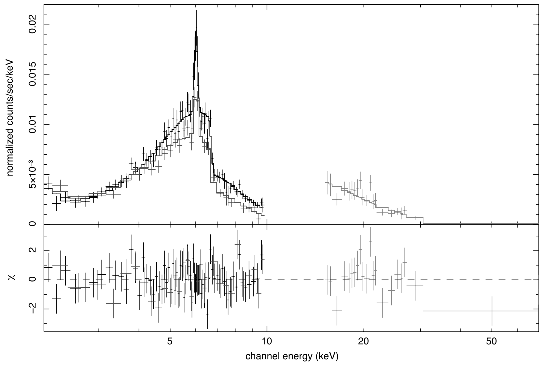


Fig. 1. *Suzaku* XIS FI *(black)*, XIS BI *(red)*, and HXD PIN *(green)* spectra and residuals of 3C 33. The model fit is double partially covered primary law of photon index $\Gamma = 1.77$, and a Gaussian Fe K$\alpha$ emission line.

dex of the primary power law $\Gamma = 1.45$ is atypically flat with respect to similar radio galaxies studied by Evans et al. (2006), and the strong residuals at energies $\sim$3 keV likely necessitate a more complex spectral model. We discuss such models next.

## 2.1. Model I: Complex Neutral Absorption

We investigated the possibility that an *additional* layer of cold absorption is required to fit the broadband spectrum of 3C 33 adequately. We adopted a double partial-covering model, implemented in XSPEC/ISIS as phabs×zpcfabs(1)×zpcfabs(2)×(powerlaw+zgauss). We included a Gaussian to represent the neutral Fe K$\alpha$ line.This model provides a good fit to the spectrum ($\chi^2$=112 for 114 dof). The best-fitting parameters of this model are a power law of photon index $\Gamma$=$1.77^{+0.19}_{-0.10}$, absorbed by columns $N_{\rm H,1}$=$(2.1^{+0.6}_{-0.5}) \times 10^{23}$ cm$^{-2}$ ($f_1$=$91^{+3}_{-4}$%) and $N_{\rm H,2}$=$(6.0^{+1.7}_{-1.9}) \times 10^{23}$ cm$^{-2}$ ($f_2$=$80^{+6}_{-8}$%). Figure 1 shows the *Suzaku* spectrum and residuals for this model.

We determined the strength of any Compton reflection in the spectrum of 3C 33 by replacing the primary power law with a PEXRAV component. This neutral reflection model provided no improvement in the fit ($\chi^2$=112 for 113 dof). The best-fitting value of the reflection fraction is $R = 0$, with a 90%-confidence upper limit of R¡0.41 for an $e$-folding energy fixed at 1 GeV. The Fe K$\alpha$ line is neutral ($E$=$6.385^{+0.021}_{-0.023}$ keV) and is unresolved.

## 2.2. Model II: Warm Absorption

An alternative method of modeling the observed spectral complexity in 3C 33 is to allow the absorber to be partially ionized. We modeled the *Suzaku* spectrum as a power law, covered by a single zone of partially photoionized absorption, plus a second, unabsorbed power law to account for the low-energy flux. We included a Gaussian to represent the neutral Fe K$\alpha$ line. This model provided an excellent fit to the spectrum ($\chi^2$ = 110 for 115 dof), with a column density $N_{\rm H}$$\sim$$7.7\times10^{23}$ cm$^{-2}$ of modestly ionized gas [log($\xi$)$\sim$1.1 ergs cm s$^{-1}$] as its best-fitting absorption parameters. The best-fitting photon index of the power law is $\Gamma = 2.00 \pm 0.12$. Again, we determined the strength of any Compton reflection in the spectrum of 3C 33, and found the best-fitting value of the reflection fraction to be $R = 0$, with a 90%-confidence upper limit of R¡0.41 for an $e$-folding energy fixed at 1 GeV. The Fe K$\alpha$ line again is neutral and unresolved.

## 3. Interpretation: Compton Reflection in 3C 33 and other Radio-Loud AGN

Our results demonstrate that 3C 33 shows no signs of Compton reflection from neutral material in the inner regions of an accretion disk: there is no reflection hump at energies >10 keV, and no evidence for relativistically broadened Fe K$\alpha$ emission. Indeed, the narrow Fe K$\alpha$ line is likely to originate in a much farther region, at least 2,000 $R_{\rm s}$ from the black hole. Several models have been proposed to explain the weakness of Compton reflection continuua in radio-loud AGN, including the idea that accretion disks are highly ionized in high $\dot{M}$ systems (Ballantyne et al. 2002). In this case, the reflection fraction remains high ($R$$\sim$1), but the ionized accretion-disk surface results in a low *measured* $R$. An alternative interpretation (Garofalo et al. 2009) is that the black holes in 'high-excitation radio galaxies', such as 3C 33, have retrograde spin with respect to their accretion disks. This pushes the innermost stable circular orbit (ISCO) of the accreting material outwards, meaning that inner-disk reflection is greatly suppressed. Although we cannot distinguish between the two models in the case of 3C 33, we advertise here that we are currently working on a global interpretation of the cosmological evolution and implications of black-hole spin in radio galaxies (Garofalo, Evans, & Sambruna 2009).

## References

Ballantyne D. et al. 2002, MNRAS., 332, 45
Bettoni D. et al. 2003 A&A., 399, 869
Evans D. A. et al. 2006, ApJ., 642, 96
Evans D. A. et al. 2006b, ApJ., 653, 1121
Garofalo D. et al. 2009, ApJ., 699, 400
Garofalo D., Evans D. A., & Sambruna R. M., in prep.
Kraft R. P. et al. 2007 ApJ., 659, 1008
Miyazaki S. et al. 1996, PASJ., 48, 801
Nandra K. et al. 2007, MNRAS., 382, 194
Reeves J. N., & Turner M. J. L. 2000, MNRAS., 316, 234
Reeves J. N. et al. 2006, AN., 327, 1079
Smith E. P. et al. 1990 ApJ., 356, 399