A *Suzaku* Observation of NGC 4593: Illuminating the Truncated Disk

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Abstract

We report results from a 2007 *Suzaku* observation of the Seyfert 1 AGN NGC 4593. The narrow Fe Kα emission line has a FWHM width $\sim$ 4000 km s^{-1}, indicating emission from $>\sim$5000 $R_{\rm g}$. There is no evidence for a relativistically broadened Fe K line, consistent with the presence of a radiatively-efficient outer disk which is truncated or transitions to an interior radiatively-inefficient flow. The *Suzaku* observation caught the source in a low-flux state; comparison to a 2002 *XMM-Newton* observation indicates that the hard X-ray flux decreased by 3.6, while the Fe Kα line intensity and width σ each roughly halved. One possibility is that the line profile in the *XMM-Newton* observation consists of a time-invariant narrow component, plus a broad component originating from the inner part of the truncated disk ($\sim$300 $R_{\rm g}$) which has responded to the drop in continuum flux. The Compton reflection component strength R is $\sim$ 1.1, consistent with the measured Fe Kα line total equivalent width with an Fe abundance 1.7 times the solar value. The modest soft excess, modeled well by either thermal bremsstrahlung emission or by Comptonization of soft seed photons in an optical thin plasma, has fallen by a factor of $\sim$20 from 2002 to 2007, ruling out emission from a region 5 light-years in size.

Key words: galaxies: Seyfert — galaxies: individual (NGC 4593)

1. Introduction

The X-ray bright Seyfert NGC 4593 is long suspected of hosting a geometrically-thin, optically-thick accretion disk which is truncated and may surround an inner radiatively-inefficient advection-dominated accretion flow (ADAF). Such configurations are thought to exist in compact systems accreting at relatively low values relative to Eddington (e.g., Esin et al. 1997). Lu & Wang (2000)'s modeling of the optical/UV thermal continuum of NGC 4593 indicated a radiatively-efficient, geometrically-thin disk truncated at 30 $R_{\rm g}$.

The Fe Kα emission line at 6.4 keV is another key tracer of the radiatively-efficient circumnuclear accreting material in AGN. An *XMM-Newton* observation of NGC 4593 in 2002 (Brenneman et al. 2007) revealed a narrow Fe Kα line originating from a radius at least 1000–2000 $R_{\rm g}$, though no relativistically-broadened Fe Kα diskline was detected.

Goals of our *Suzaku* observation in December 2007 included constraining the Fe Kα profile and the level of Compton reflection, and searching for a relativistically broadened Fe line. In addition, the *Suzaku* observation caught the source during a low-flux state, giving us the opportunity to test if emission components respond to the drop in X-ray continuum flux. Good time exposures were 118 ksec per XIS & 90 ksec for the HXD/PIN.

2. Modeling the 0.3–76 keV *Suzaku* Spectrum

Our best-fit model to the 0.3–76 keV *Suzaku* spectrum includes: A power-law component ($\Gamma = 1.65 \pm 0.21$); a warm absorber with $N_{\rm H} \sim 3 \times 10^{21}$ cm^{-2} and log $\xi \sim$ 2.4 erg cm s^{-1} (McKernan et al. 2003; Steenbrugge et al. 2003); a Compton reflection component (pexrav); a soft excess modeled equally well with either thermal Bremsstrahlung ($k_{\rm B}T \sim$ 200 eV) or thermal Comptonization ($k_{\rm B}T \sim$ 50 eV); and narrow Fe Kα and Fe Kβ emission lines, modeled with Gaussians.

The Compton reflection strength R was 1.08 $\pm$ 0.20 (statistical uncertainty only; $\pm$ 0.35 including systematic uncertainty associated with the PIN background). The Fe Kα FWHM width is $\sim$4000 km s^{-1}. Assuming a black hole mass $M_{\rm BH} = 6.6 \times 10^6$ solar masses (from the $M_{\rm BH}$-σ_* relation & Nelson et al. 2004), the emission originates from a radius $>\sim$ 5000 $R_{\rm g}$. There is no evidence for a relativistically broadened Fe K line (*EW* $<$ 40 eV), consistent with the presence of a radiatively-efficient outer disk which is truncated or transitions to an inner ADAF, and in agreement with Brenneman et al. (2007). Furthermore, models with blurred, ionized disk reflection were unable to consistently fit the Compton hump and soft excess.

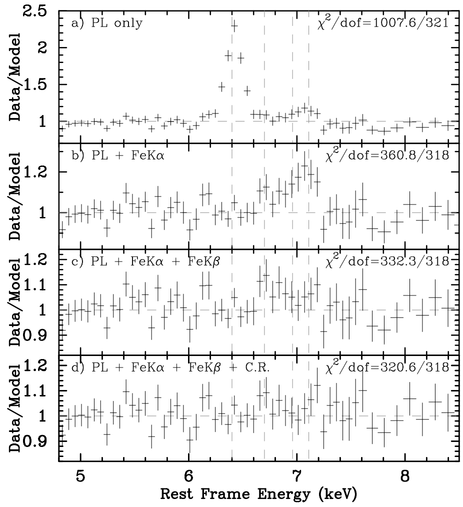

Fig. 1. Data/model residuals to fits to the *Suzaku* XIS-FI Fe K bandpass spectrum. Data are rebinned by a factor of 4. Panel a shows residuals to a simple power-law fit. Panel b shows residuals when the Fe Kα line is included. In panel c, the Fe Kβ line has been included. In panel d, a Compton reflection component, containing an Fe K edge at 7.11 keV, has been included; this is our best-fit model. Vertical dashed lines denote the expected energies of Fe I Kα, Fe XXV, Fe XXVI, and Fe I Kβ emission lines.

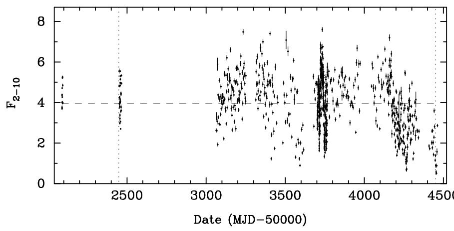

Fig. 2. 2–10 keV light curve from public archive *RXTE*-PCA monitoring. Flux is in units of 10^{-11} erg cm^{-2} s^{-1}. The horizontal dashed lin e denotes the long-term average mean flux of 3.9×10^{11} erg cm^{-2} s^{-1}. Vertical dashed lines denote the times of the 2002 *XMM-Newton* and 2007 *Suzaku* observations.

3. Comparison to the 2002 *XMM-Newton* pn spectrum

NGC 4593's long-term average 2–10 keV flux (F_{2-10}) from *RXTE*-PCA monitoring is 3.9×10^{-11} erg cm^{-2} s^{-1}, the same flux as during the *XMM-Newton* observation. However, the *Suzaku* observation caught the source in a low-flux state (see Fig. 2): compared to the flux during the *XMM-Newton* observation, F_{2-10} decreased by 3.6, and Fe Kα line intensity and width σ each decreased by $\sim$2. The two lines widths are inconsistent up to the $\Delta\chi^2 = 9.5$ (>99.7%, or >3σ) confidence level. Given that the XIS and the pn have roughly similar energy resolution & effective areas near 6 keV, the evolution in line width is likely intrinsic to the source. Applying the best-fit broadband model to the 2002 *XMM-Newton* pn spectrum, 0.2–12 keV, we find that the soft excess decreased in normalization by $\sim$10–20 from 2002 to 2007, ruling out emission from a region 5 lt-yrs in size.

Two model-dependent explanations for the change in Fe Kα profile from 2002 to 2007 are explored. First we considered a "single-Gaussian" model, in which the Fe Kα profile consists of a single emission component. The transition radius has increased from $\sim$1000–2000 R_g in 2002 to $>\sim$5000 R_g in 2007, causing the observed Fe Kα FWHM width to drop from $\sim$10000 to $\sim$4000 km s^{-1}. However, in other compact accreting systems, such large truncation radii tend to be associated only with values of L_{Bol}/L_{Edd} a few orders of magnitude lower than that of NGC 4593 ($L_{Bol}/L_{Edd} = 5.5\%$), e.g., Yuan & Narayan (2004). It's also not clear whether the inner portion of a thin disk in AGN can evaporate or become an ADAF in only 5 years. As the accretion disks of BH XRBs likely evolve on time scales of at least hours to days, the corresponding time scales in NGC 4593 ($M_{BH} = 10^5$ higher) would be decades to centuries. We also invoked a "dual-Gaussian" model to separate variable and constant emission components in the line profile. We remodeled the line profile observed with *XMM-Newton* in 2002 as consisting of a time-invariant narrow component originating no closer than $\sim$3000 R_g (further may be more likely) which has not responded to the drop in F_{2-10}, plus a broad component from the inner disk ($\sim$300 R_g), which has responded to the drop in F_{2-10} by 2007. This explanation seems more physically plausible.

4. Constraints on the X-ray continuum source

Assuming the "lamppost" geometry with an X-ray continuum point source on the symmetry axis a height h above the disk, then if the thin disk is truncated at several thousand R_g, then, in order to create sufficient Fe fluorescence to match the *EW* of the observed Fe Kα line, the X-ray continuum source must be located at a height h of several thousand R_g (following George & Fabian 1991). A configuration in which the X-ray corona is associated with the base of a jet along the symmetry axis may thus be applicable, e.g., Markoff et al. (2005).

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