Complex Circumnuclear Structures in the Radio-Loud AGN Mkn 6

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Summary

Mkn 6 is a radio-loud Seyfert with sustained, recurrent radio activity. Its jet may have recently changed direction, in which case the accretion structure may not be fully shielded, and one might expect a complex torus/cir-
cumnuclear environment. Mkn 6’s X-ray spectrum does in fact consistently display coverage by a small number of hard X-ray absorption features, which includes a Compton-thick absorption component (Mingo et al. 2011, ApJ, 731, 21). Here, we present preliminary results from two new broadband NuS-
TAR/Suzaku and NuSTAR/Swift observations in 2015, including the first high-energy data on the X-ray properties of the nearly-simultaneous line-of-sight X-ray-absorbing structures and X-ray-refracting gas to expand on previous results. We derive a unique set of model parameters that includes full-covering Compton-thin absorption (N_H = 1 × 10^{23} cm^{-2}); partial-covering Compton-medium absorption (N_H = 0.6–6 × 10^{23} cm^{-2}); and Compton-thick absorption (N_H = 8 × 10^{22} cm^{-2}). In addition, we have provided support for a new generation of clumpy-torus models (D. E. Martin et al. 2016, ApJ, 848, L101), and we now test them in radio-loud Seyferts. Mkn 6 may thus be a radio-loud analog of NGC 1365, as well as a radio-loud Seyfert. We applied our best-fit model to archival data: 1996 June; 2010 October; 2011 June; 2015 April; 2015 November; and 2015 November NuSTAR. Results are summarized in Table 1.

Observations & Spectral Fitting Results

NuSTAR observed Mkn 6 simultaneously with Swift/XRT in November 2015, each yielding 0.5–50 keV spectra. Our best-fit model uses MYTORUS components (Murphy & Vaughan 2009, MNRAS, 397, 1549) and Swift/XRT, and we disentangle line-of-sight absorption, X-ray continuum emission, and reflection component emanating from clouds on the far side of the SMBH. Column densities span 0.1–10^{21} cm^{-2}.

We interpret component B as partially-covering clumps. Their reflection component emanates from clouds on the far side of the SMBH. Column densities span 0.1–10^{21} cm^{-2}.

2001 Apr. XMM EPIC/Pn 1.15 × 10^{-11} (ph s^{-1} cm^{-2}) 1.35 × 10^{-11} (ph s^{-1} cm^{-2}) 0.84 × 10^{-11} (ph s^{-1} cm^{-2}) 85% 1.82 × 10^{-10} 2.90
2003 Apr. XMM EPIC/Pn 1.28 × 10^{-11} (ph s^{-1} cm^{-2}) 1.7 × 10^{-11} (ph s^{-1} cm^{-2}) 0.63 × 10^{-11} (ph s^{-1} cm^{-2}) 65% 1.87 × 10^{-10} 3.52
2005 Oct. XMM EPIC/Pn 1.54 × 10^{-11} (ph s^{-1} cm^{-2}) 3.8 × 10^{-11} (ph s^{-1} cm^{-2}) 93% 1.77 × 10^{-10} 1.71
2013 Apr. NuSTAR FFPA/B Suzaku XIS 4.53 × 10^{-12} (ph s^{-1} cm^{-2}) 8.53 × 10^{-12} (ph s^{-1} cm^{-2}) 6.2 × 10^{-12}(ph s^{-1} cm^{-2}) 72% 1.74 × 10^{-11} 3.15
2013 Nov. NuSTAR FFPA/B Suzaku XIS 8.1 × 10^{-12} (ph s^{-1} cm^{-2}) 3.15 × 10^{-12} (ph s^{-1} cm^{-2}) 6.2 × 10^{-12}(ph s^{-1} cm^{-2}) 68% 1.87 × 10^{-11} 3.51

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Table 1: Summary of Spectroscopic Observations and Swift XRT Observations.

Interpretation

We interpret component B as partial-covering clumps. Their reflection component emanates from clouds on the far side of the SMBH. Column densities span 0.6–6 × 10^{23} cm^{-2}. Covering fraction measurements are usually 61–77%, but reach extremes of 30% & 98%. Because they only partially cover the X-ray corona, clouds must be < few tens of R_S (from M94 = 1.4 × 10^{20} M_{Sun}; C.J. Gierl et al. 2012, ApJ, 755, 60, e.g., R_S = 30 R_S = 6 × 10^{23} cm). Cloud number densities are typically order 10^3 cm^{-3}.

The clouds are likely close to the SMBH but are neutral or low-ionization; constraints on ionization parameter imply a distance d_{SMBH} > 9 kpc. This limit is commensurate with the BLR H\alpha emission (9–10 kpc; G. E. Chini et al. 2012), but also encompasses the dusty torus (dust sublimation radius of 100–210 kpc, from IR reverberation mapping & IR interferometry, M. Kishimoto et al. 2011, A&A, 527A, 121). We consider the clumpy-torus model of Nenkova et al. (2008, ApJ, 685, 160), in which clouds are preferentially distributed towards the equatorial plane, and our observations span a range of numbers of clouds in the line of sight. Given that CF\gamma is never observed to be 0% or 100%, we’re not seeing only one clump in any given observation — likely a few. If individual clouds each have typical covering fractions of (arbitrary values) 10% (30%), then XMM\gamma (30%) component is consistent with an ordered component of 0.3–1.5% in the jet, which is scattered away from the optical- thin, high-energy jet. r = 0.01–0.02; a possible origin is the kpc-scale Extended Narrow Line Region traced by [O iii] (Rokuhi et al. 1996).

Component A is a full-covering Compton-thin gas, N_H = 1 × 10^{23} cm^{-2}; the range in values is likely due to systematic differences between instruments; its origin (close to the SMBH vs. associated with the host galaxy) is thus unclear.

Component B denotes Compton-thick matter, N_H = 4 × 10^{22} cm^{-2}, which does NOT intersect the line of sight in any of the six observations. Although we cannot determine its exact morphology, a tilted dust or tilted cloud distribution is possible. The HXPL component is not 2–50 keV luminosity consistent with illuminating this component.

Main Conclusions

We successfully applied a self-consistent absorption + reflection model to two newly-
obtained joint NuSTAR/Suzaku and NuSTAR/Swift observations in 2015 plus archival CCD-quality data 2001–8. Our preferred model features full-covering Compton-thin absorption Na\gamma = 1 × 10^{23} cm^{-2}; partial-covering Compton-medium gas (N_H = 0.6–6 × 10^{23} cm^{-2}; CF\gamma spanning 30–95%) but usually 61–77%, and reflection from Compton-thick gas N_{\gamma C} = 4 × 10^{22} cm^{-2} lying out of the line of sight.

Spectral variability is primarily attributed to a combination of intrinsic variations in power-law (factor of 3.4) and in CF\gamma, and possibly mild variability in N_{\gamma C}.

We attribute Component B to clumps near the SMBH, possibly BLR clouds. Mkn 6 is thus possibly a radio-loud analog of NGC 1365, which frequently displays exceptional X-ray spectral variability, and may benefit from a relatively favorable combination of geometry/tying angle and/or a mechanism that produces such variability. For all, the data in the six clouds in Mkn 6 have roughly similar values of N_{\gamma C}. However, if a set of Compton-thick clouds with high covering fractions were to traverse the line of sight, we could temporarily have a “changing-look” Seyfert.