The Spectral Energy Distributions of AGN with Double-Peaked Balmer Lines

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Abstract. We summarize the optical, UV, and X-ray properties of double-peaked emitters – AGN with double-peaked Balmer emission lines believed to originate in the AGN accretion disk. We focus on the X-ray spectroscopic results obtained from a new sample of the 16 broadest Balmer line AGN observed with Chandra and Swift.

1. Introduction

Forty years of research on the Broad Line Regions (BLRs) of Active Galactic Nuclei (AGN) has not yielded a clear picture of the structures and detailed physical conditions involved in setting the observed line profiles and strengths. Our current understanding involves contributions from an outflowing, likely clumpy, magnetohydrodynamically or line-driven wind, and an accretion disk (e.g. Collin et al. 2006). The BLR is photoionized and must intercept at least 10% of the radiation from the central engine to produce lines of the observed strengths. If the accretion disk contributes to the BLR emission from AGN, we expect to see a clear signature of this contribution in the form of a double-peaked line profile, distorted by the effects of Doppler boosting and gravitational redshift.

2. Optical and UV Properties of Double-Peaked Emitters

About 3% of optically selected AGN have H$\alpha$ lines with the characteristic double-peaked shape consistent with accretion-disk emission (Strateva et al. 2003, hereafter S03). Among broad-line radio galaxies this fraction is up to 20% (Eracleous et al. 2003, hereafter E03), suggesting that Balmer-line accretion-disk emission is more prevalent among AGN with jets and lower luminosities/accretion rates.

As a class double-peaked emitters are characterized by broader Balmer lines (up to 40,000 km s$^{-1}$ full width at half maximum [FWHM]), similar UV/optical luminosities to those of other AGN in the same redshift range, and a higher incidence of LINER characteristics – for example, larger low-ionization line ratios and low-ionization line equivalent widths ([O I] 6300Å/[O III] 5007Å, [S II] EWs,
etc.; E03, S03). Lewis et al. (2006) report the black-hole masses of 8 double-peaked emitters based on the stellar velocity dispersions of their host-galaxy bulges and find that the accretion rates as a function of Eddington vary considerably even in this small sample, with $10^{-5} < L/L_{\text{Edd}} < 0.1$. UV observations of double-peaked emitters often show single-peaked high-ionization lines (e.g. C III], CIV, Lyα; Halpern et al. 1996), and are likely dominated by emission from the outflowing BLR component.

Figure 1. Optical (left panels; both the AGN and AGN+host-galaxy spectra are shown) and X-ray spectra (right panels) of two of the Swift targets.

Axisymmetric accretion-disk fits to the Hα line profiles of about 3 dozen objects from the E03 and S03 samples constrain the accretion-disk line emission to originate between a few hundred and a few thousand $R_G$ (gravitational radii) from the center. The outer radii of emission, typically $\lesssim 4000 R_G$, are consistent with the onset of disk self gravity. The disk inclinations range between $20^\circ < i < 75^\circ$ (from the accretion-disk axis), with the inclination distribution suggestive of the presence of coplanar obscuration, whose probability becomes exponentially higher for large inclinations. This is consistent with clumpy unification models (see the Elitzur, Sturm, and Hao contributions in this volume).

3. X-ray Properties of Double-Peaked Emitters

Strateva et al. (2006) [S06] studied the X-ray emission of 39 double-peaked emitters, serendipitously detected in ROSAT (22/39), Chandra and XMM-Newton observations. As a class the double-peaked emitters showed similar UV/optical-to-X-ray ratios ($\alpha_{\text{ox}} = 0.3838 \log [F_{2\text{keV}}/F_{2500\AA}]$) and X-ray power-law spectral indices to other broad-line AGN. In practically all cases (see Fig. 3b) a comparison of the Hα emission strength with the viscous power available locally

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1The outer emission radii are often poorly constrained due to a degeneracy between the disk outer radius and the power-law slope of the illuminating radiation.
from the accretion disk supports the need for external illumination of the disk to produce lines of the observed strength.

4. New Chandra and Swift Observations

Our Chandra(5/16)/Swift(11/16) sample consists of the 16 double-peaked emitters with the broadest Balmer lines (FWHM$_{H\alpha} > 15,000$ km s$^{-1}$) ever observed. The Balmer-line emission in these AGN originates from the immediate vicinity of the black hole, immediately adjacent to the region responsible for the X-ray emission and the external illumination. Fig. 1 shows the optical and X-ray spectra of two radio-quiet [RQ] double-peaked emitters. Despite their comparable 4200Å luminosities their X-ray spectra are strikingly different – with large cold absorption modifying the power-law emission in one case, but not in the other ($5 \times 10^{20}$ cm$^{-2}$ and $10^{23}$ cm$^{-2}$ for the top and bottom spectra, respectively). Half of the Chandra/Swift sample objects show intrinsic X-ray absorption.

Figure 2. Left: The 2500Å vs. 2 keV monochromatic luminosities of the Chandra/Swift targets (circles), the double-peaked emitters from S06 (triangles and squares), and the general SDSS AGN population (small dots). The open symbols denote RL AGN, the solid symbols RQ AGN, and the arrows upper limits. Right: The $\alpha_{\text{ox}}$ residual distributions for the RQ double-peaked emitters (top), the general SDSS lower-luminosity population (middle) and the RL double-peaked emitters (bottom). The solid histograms in the top and bottom panels show only the Chandra/Swift samples, while the open histogram indicates X-ray limits.

The X-ray power-law spectral indices of extremely broad double-peaked emitters are similar to those of other double-peaked emitters and normal AGN with comparable radio-loudness. Unlike the general sample of double-peaked emitters, however, the broadest Balmer-line double-peaked emitters appear X-ray brighter relative to other AGN with comparable UV emission (see Fig. 2). In
Fig. 3. **Left:** The intrinsic X-ray absorption (arrows indicate limits based on the Galactic absorption) vs. the Hydrogen column inferred from the NLR Balmer decrement; the dashed line is a line of equality. **Right:** The distribution of the ratio of line-strength ($L_{H\alpha}$) and locally available viscous power ($W_{\text{disk}}$) for the Chandra/Swift targets (solid histogram) and the E03 and S06 objects (hatched). A ratio larger than 10% (solid line) indicates the need for external illumination.

Fig. 2b we quantify this difference by comparing the $\alpha_{\text{ox}}$ residual distributions for RQ and radio-loud [RL] double-peaked emitters to those of normal SDSS AGN with comparable luminosities. RL AGN are brighter in the X-rays than similar UV luminosity RQ AGN regardless of their Balmer-line shapes (i.e. they have larger $\alpha_{\text{ox}}$ residuals). After the addition of the broadest Balmer-line double-peaked emitters to the objects in S06, we now find a statistically significant difference (99%) for the RQ double-peaked emitters, which are also X-ray brighter.

Fig. 3a shows the X-ray absorbing-gas column vs. the hydrogen column estimated based on the optical reddening (via the narrow line region [NLR] Balmer-line decrements). In a handful of double-peaked emitters (those close to the dashed line in Fig. 3a) the observations are consistent with a single absorber with gas-to-dust ratio similar to that of the interstellar medium in our Galaxy (e.g. the AGN host galaxy). In at least 3 cases the X-ray absorbing column is much higher, possibly indicating a dust-free or a partial absorber on scales much smaller than the NLR.

References

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$^2$The $\alpha_{\text{ox}}$ residuals are obtained by subtracting the $\alpha_{\text{ox}}$ dependence on luminosity measured by Steffen et al. (2006) for RQ AGN, $\alpha_{\text{ox}} = -0.137 \log[L_{2500\AA}] + 2.638$, from the measured $\alpha_{\text{ox}}$. 
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