NuSTAR Reveals the Comptonizing Corona of the Broad-Line Radio Galaxy 3C 382

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Abstract: Broad-line radio galaxies (BLRGs) are AGNs that produce powerful, large-scale radio jets, but appear as Seyfert 1 galaxies in their optical spectra. In the X-ray band, BLRGs also appear like Seyfert galaxies, but with flatter spectra and weaker reflection features. We present 2 NuSTAR observations of the BLRG 3C 382 that show clear evidence that the continuum is dominated by thermal Comptonization, as in Seyfert 1 galaxies. The 2 observations were separated by over a year and a factor of 1.7 in flux. The lower flux spectrum has a $\Gamma=1.68^{+0.03}_{-0.02}$ while the higher flux spectrum has a $\Gamma=1.78^{+0.02}_{-0.03}$. Thermal and anisotropic Comptonization models provide an excellent fit to both spectra and show that the coronal plasma cooled from $kT=330\pm30$ keV in the low flux state to $231^{+88}_{-50}$ keV in the high flux observation. This cooling behavior is typical of Comptonizing corona in Seyfert galaxies and is distinct from the variations observed in jet-dominated sources. In the high flux observation, simultaneous Swift data are leveraged to obtain a broadband SED and indicates that the corona intercepts ~10% of the optical and UV emitting accretion disk. 3C 382 exhibits very weak reflection features that may be best explained by an outflowing corona combined with an ionized inner accretion disk.

Introduction:

- Broad-line radio galaxies (BLRGs) are the brightest unobscured jetted AGNs.
- In the X-ray band they have consistently shown weaker reflection features and flatter X-ray spectra than typical Seyfert 1 galaxies (e.g., Eracleous et al. 2000; Grandi et al. 2001; Ballantyne 2007; Evans et al. 2010).
- Proposed explanations for these differences include:
  1) High inner disk ionization (Ballantyne et al. 2002).
  2) A truncated accretion disk (Eracleous et al. 2000; Lohfink et al. 2013).
  3) Obscuration of the inner disk by the radio jet (Sambruna et al. 2009).
  4) Black holes with retrograde spin (Garofalo et al. 2010).
- Broad-line radio galaxies (BLRGs) are AGNs that produce powerful, large-scale radio jets, but appear as Seyfert 1 galaxies in their optical spectra. In the X-ray band, BLRGs also appear like Seyfert galaxies, but with flatter spectra and weaker reflection features. We present 2 NuSTAR observations of the BLRG 3C 382 that show clear evidence that the continuum is dominated by thermal Comptonization, as in Seyfert 1 galaxies. The 2 observations were separated by over a year and a factor of 1.7 in flux. The lower flux spectrum has a $\Gamma=1.68^{+0.03}_{-0.02}$ while the higher flux spectrum has a $\Gamma=1.78^{+0.02}_{-0.03}$. Thermal and anisotropic Comptonization models provide an excellent fit to both spectra and show that the coronal plasma cooled from $kT=330\pm30$ keV in the low flux state to $231^{+88}_{-50}$ keV in the high flux observation. This cooling behavior is typical of Comptonizing corona in Seyfert galaxies and is distinct from the variations observed in jet-dominated sources. In the high flux observation, simultaneous Swift data are leveraged to obtain a broadband SED and indicates that the corona intercepts ~10% of the optical and UV emitting accretion disk. 3C 382 exhibits very weak reflection features that may be best explained by an outflowing corona combined with an ionized inner accretion disk.

The Target & Observations:

<table>
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<tr>
<th>Telescope</th>
<th>UT Start Date</th>
<th>Exposure (ks)</th>
<th>Counts</th>
</tr>
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<tbody>
<tr>
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<td>High flux</td>
<td>2012 Sept 18</td>
<td>3678</td>
</tr>
<tr>
<td>Observation 2</td>
<td>Low flux</td>
<td>2013 Dec 18</td>
<td>6396681219</td>
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</tbody>
</table>

For the NuSTAR observations, exposure times and counts are listed for the 2 focal plane modules (FPMA/FPMB). Observation 1 also requires a blackbody component to fit a soft excess. Results are consistent with the Suzaku analysis of Sambruna et al. (2011).

Spectral Analysis & Results:

- Both observations show weak reflection ($R=0.16$ and 0.03 for Obs. 1 & 2, respectively) and a prominent, but relatively narrow, Fe Kα line.
- Spectra are well fit by a model that includes a cutoff powerlaw and a Fe Kα emission line.
- The corona is cooler when the source is brighter.

Figure 1: (Top) Count rate spectra of 3C 382 and the background for Obs. 1 for NuSTAR FPMA (black), FPMB (red), and Swift-XRT (green). The residuals are shown for a power-law model modified by Galactic absorption and a weak warm absorber. Data between 4 and 7.5 keV are not included in the fit. (Bottom) Same as top except for Obs. 2.

Figure 2: The 68% (solid), 90% (dotted) and 95% (dashed) joint confidence contours on $kT_e$ and $\Gamma$ calculated from the best fitting compss+ 6.4 keV Gaussian models. The corona is cooler when the source is brighter.

Figure 3: Predicted optical/UV/X-ray SED for Obs. 1 as determined by the compss models. Galactic absorption has been removed, but the small effects of the warm absorber are still visible. To highlight the Comptonization spectra, the full SED has been decomposed into the compss continuum (solid lines), the soft excess and the Fe Kα line (dashed lines). The different colors indicate different coronal geometries: slab, cylinder, hemisphere, and sphere. The same seed photon distribution (diskbb with $kT=8.9$ keV) was used for all models. The data points are from the Swift/UVOT observations obtained during Obs. 1 and have been corrected for Galactic and internal extinction. The UV emission predicted by the Comptonization models is from the 0° scattering order, which, in a low $\Gamma$ corona such as 3C 382, is nearly equal to the total UV emission necessary to produce the observed X-rays. Thus, the X-ray corona intercepts only ~10% of the UV flux from the accretion disk.

References:
- Ballantyne, D.R., 2007, MPLA, 22, 2397

Acknowledgments: This work was supported under NASA Contract No. NNG08FD60C, and made use of data from the NuSTAR mission, a project led by the California Institute of Technology managed by the Jet Propulsion Laboratory, and funded by the National Aeronautics and Space Administration. We thank the NuSTAR Operations, Software and Calibration teams for support with the execution and analysis of these observations. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. The NuSTAR Data Analysis Software (NuSTARDAS) jointly developed by the ASDC (ASDC, Italy) and the USC (Columbia Univ., USA) was used for the analysis of these data. This research has made use of data obtained from the Chandra Data Archive, which is operated by the Smithsonian Astrophysical Observatory under NASA contract number NAS8-03060. This work made use of the Data Center for Active Galactic Nuclei (CDS) at the University of Leiden, The Netherlands. This work was supported under NASA Contract No. NNG08FD60C, and made use of data from the NuSTAR mission, a project led by the California Institute of Technology managed by the Jet Propulsion Laboratory, and funded by the National Aeronautics and Space Administration. We thank the NuSTAR Operations, Software and Calibration teams for support with the execution and analysis of these observations. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology (USA). This work made use of data supplied by the UK Swift Science Data Centre at the Royal Observatory, Edinburgh. CDFW acknowledges support from NASA/SSP grant NNX10AR12G and NSF award AST 1008067. AM acknowledges financial support from Italian Space Agency under grant ASI/INAF I/037/12/0-011/13 and from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 312789. M. B. acknowledges support from the International Fulbright Science and Technology Award.