New insights on the accretion disk-winds connection in radio-loud AGNs from Suzaku

Francesco Tombesi
NASA/GSFC/CRESST, Greenbelt, MD (USA)
University of Maryland, College Park, MD (USA)


“Exploring the X-ray Universe: Suzaku and Beyond”, SLAC, July 20-22 2011
Recent evidence for blue-shifted Fe K absorption lines at E>7keV in the X-ray spectra of Seyferts/QSOs (e.g., Chartas et al. 2002, 2003; Pounds et al. 2003; Dadina et al. 2005; Markowitz et al. 2006; Braito et al. 2007; Turner et al. 2008; Cappi et al. 2009; Reeves et al. 2009)

Ultra-fast Outflows (UFOs) with velocities ~0.1c, connected with accretion disk winds/outflows. Possibly important for AGN cosmological feedback (e.g., King 2010)

Systematic 4-10keV spectral analysis on a complete sample of 42 Seyferts, 101 XMM-Newton observations (Tombesi et al. 2010a)

- Global statistical significance lines is high (>5σ) and solved publication bias
- Detection frequency >40%, possibly large covering fraction and not collimated
X-ray evidence for ultra-fast outflows in radio-quiet AGNs

Xstar photo-ionization modeling and curve of growth analysis of UFOs, distributions of absorber parameters in Seyferts (Tombesi et al. 2011, ApJ accepted)

- Ultra-fast, outflow velocity $\sim$0.03-0.3c, mean $\sim$0.14c
- Highly ionized, $\log \xi \sim$2.5-6 erg s$^{-1}$cm, mean $\sim$4.2 erg s$^{-1}$cm
- Large column density, $N_H \sim 10^{22}-10^{24}$ cm$^{-2}$, mean $\sim 10^{23}$ cm$^{-2}$
Suzaku discovery of ultra-fast outflows in radio-loud AGNs

- Broad Line Radio Galaxies are the radio-loud counterpart of Seyfert 1s
- Show observable strong relativistic radio jets
- Limited observations in X-ray archives to five “classical” sources
- 3C 111, 3C 390.3, 3C 120, 3C 382, 3C 445

Systematic spectral analysis (Tombesi et al. 2010b):

- Suzaku long (>100ks) observations
- 4-10 keV XIS spectral analysis
- Search for blue-shifted Fe K absorption lines
- Fe XXV/XXVI K-shell series lines at E>7keV in 3/5 sources
- High detection probability from F-test and Monte Carlo simulations, >99%
Suzaku discovery of ultra-fast outflows in radio-loud AGNs

Photo-ionization modeling of Fe K absorbers

<table>
<thead>
<tr>
<th>Source</th>
<th>$\log \xi$ (erg s$^{-1}$ cm)</th>
<th>$N_H$ ($10^{22}$ cm$^{-2}$)</th>
<th>$v_{out}$ (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C 111</td>
<td>$5.0 \pm 0.3$</td>
<td>$&gt;20^a$</td>
<td>$+0.041 \pm 0.003$</td>
</tr>
<tr>
<td>3C 390.3</td>
<td>$5.6^{+0.2}_{-0.8}$</td>
<td>$&gt;3^a$</td>
<td>$+0.146 \pm 0.004$</td>
</tr>
<tr>
<td>3C 120b</td>
<td>$3.8 \pm 0.2$</td>
<td>$1.1^{+0.5}_{-0.4}$</td>
<td>$+0.076 \pm 0.003$</td>
</tr>
</tbody>
</table>
Suzaku discovery of ultra-fast outflows in radio-loud AGNs

Physical characteristics of UFOs in BLRGs:

• Common, detected in 3/5 sources
• Compact and close to the BH, d<0.01-0.1pc (<100-1000r_g)
• Expected variability on ~ days, duty cycle?
• Covering fraction roughly ~0.5, similar to Seyferts
• Massive, instantaneous $M_{\text{out}} \sim 1M_{\odot} \text{yr}^{-1} \sim M_{\text{acc}}$
• Powerful, $E_K \sim 10^{43}-10^{45}$ erg/s ~ radio jet power
• $L_{\text{bol}}/L_{\text{Edd}} \sim 0.1-0.5$, force multiplier $\Gamma$?
• wind/photon momentum, $(M_{\text{out}}v_{\text{out}})/(L_{\text{bol}}/c) \geq 1$
• Radiation pressure important, but possible additional magnetic thrust to reach higher velocities
• Role on AGN feedback? (e.g., King 2010)

(Ohsuga et al. 2009)
Follow-up 3C 111: Suzaku proposal GO5 to monitor predicted UFO variability on ~7 days time-scales

Tombesi et al. (2011, in prep.)

- 3 x 60ks Suzaku observations, september 2010
- 30% flux variability between Obs1 and Obs2
- 4-10 keV XIS spectral analysis, power-law continuum $\Gamma \sim 1.7$ and 6.4keV Fe K
- Detection emission line $E=6.88$keV in Obs1, absorption line $E=7.75$keV in Obs2
- High significance, >99.9% from F-test and Monte Carlo simulations
- Constancy emission/absorption lines excluded at 99.7% and 99.9%
Accretion disk-outflow connection in 3C 111 with Suzaku

**Obs1**
- Ionized relativistic line (relline profile)
- Bulk emission possibly from Fe XXV/XXVI
- Reflection from accretion disk $\sim 20-100r_g$, inclination $\sim 18^\circ$

**Obs2**
- Ultra-fast Outflow (Xstar modeling)
- Velocity $v_{\text{out}}=0.106\pm0.006c$
- $\log \xi=4.32\pm0.12$ erg s$^{-1}$cm, Fe XXVI
- $N_H=(7.7\pm2.9)\times10^{22}$ cm$^{-2}$
Accretion disk-outflow connection in 3C 111 with Suzaku

- Variability ~7 days, d<0.006pc (<50-500 rg, \( M_{\text{BH}} \sim 3 \times 10^9 \) or \( 2 \times 10^8 M_{\odot} \))
- Ionized reflector, \( n>10^9 \text{cm}^{-3}, N_H>10^{25} \text{cm}^{-2} \)
- Ultra-fast Outflow ~0.1c, for C~0.5, \( M_{\text{out}} \sim 1 M_{\odot} \text{yr}^{-1} \sim M_{\text{acc}} \)
- \( E_K \sim 5 \times 10^{44} \text{erg/s}, \) comparable radio jet power
- \( L_{\text{bol}}/L_{\text{Edd}} < 0.3, E_K/L_{\text{bol}} \sim 0.06 \)
- Wind/photon momentum, \( (M_{\text{out}} v_{\text{out}})/(L_{\text{bol}}/c) \sim 1 \)
- Photospheric radius for \( \tau \sim 1, \) momentum deposition ~100rg

- First direct evidence for accretion disk-outflow connection in an AGN
  - Increased illumination inner part accretion disk due to rise in accretion rate Obs1-Obs2
  - Outflow lifted from disk at ~100rg, acceleration to ~0.1c by radiation pressure Obs1-Obs2
  - Superluminal source and inclination ~18°, possible plasma additional magnetic acceleration

- Under investigation
  - Connection with radio jet? External layers, collimation, shocks? (e.g., Chattergee et al. 2011)
  - Coupling between accretion disk, outflows and jets? (e.g., GRS 1915+105 Neilson & Lee 2009)
  - Role on AGN cosmological feedback? (e.g., King 2010) Additional monitoring required!
The Suzaku view of 3C 382

• Broad-band Suzaku (116ks) + Swift BAT 58-month, E=0.6-200keV (Sambruna et al. 2011)

• Continuum similar to Seyferts, $\Gamma \sim 1.8$ and cut-off $E \sim 200$keV, Comptonization in corona

• Emission lines Fe K band: Fe K\text{\textalpha} $\sim 6.41$keV, Fe K\text{\textbeta} $\sim 7.06$keV, Ni K\text{\textalpha} $\sim 7.5$keV ($P_F > 99.99\%$

• Ionized relativistic Fe K emission line profile: $r_{\text{in}} = 12 \pm 2 r_g$, $r_{\text{out}} = 23 \pm 3 r_g$, $i = 30^\circ \pm 1^\circ$ ($P_F > 99.99\%$

• (1) Mildly ionized $\log \xi = 1.54 \pm 0.03$, $R_F \sim 0.1$, $n \sim 5 \times 10^7$cm$^{-3}$, $d \sim 0.3$pc (BLR or inner torus)

• (2) Highly ionized $\log \xi = 2.93 \pm 0.04$, $R_F \sim 0.1$, $n \sim 10^{11}$cm$^{-3}$, $d \sim 10-20 r_g$ (inner accretion disk)
Astro-H micro-calorimeter simulations

3C 120 Astro–H 100ks (v_turb=1000km/s, Feb 2006)

3C 111 Astro–H 100ks (v_turb=1000km/s, Aug 2008)

3C 111 Astro–H 100ks (Obs1 Sept. 2010)

3C 111 Astro–H 100ks (Obs2 Sept. 2010)
Thank you