A search for relativistic outflows signatures in the X-ray spectra of Radio-Quiet AGNs

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Active Galactic Nuclei

- Very luminous phenomena at center of galaxies
  \[ L = 10^{41} - 10^{46} \text{ erg s}^{-1} \]
- Powered by accretion onto SMBHs
  \[ M = 10^6 - 10^9 \, M_\odot \]

General structure:
- Central SMBH
- Accretion disk
- Obscuring Torus (Type 1 and 2 dicotomy)
- Outflows, winds
- Relativistic Jets (in Radio Loud Objects)

X-ray emission:
- Production region very close to SMBH
- Fundamental for the study of accretion physics (the central engine)
The complex X-ray Spectrum

Typical X-ray Spectrum of Seyfert 1 Galaxies

- Total (observed) Spectrum
- Reflection continuum
- Comptonized spectrum (≈PL + high-E cutoff)
- FeKα (diskline)
- Absorption edges (~C, N, O, etc.)
- Warin Absorber
- Disk
- Black-body
- Hot (10⁶K)
- Corona
- Cold (10⁶K) Accretion disk
- BH
X-ray outflows

Classical AGN warm absorbers:

• ~50% Seyfert Galaxies
• mainly absorption in soft X-rays (OVII/VIII, NeIX/X, Fe L)
• ionization log $\xi =$0-3 erg s$^{-1}$ cm
• outflow velocity $v =$10-1000 km/s
• column density $N_H =$10$^{20}$-10$^{23}$ cm$^{-2}$
• distance $r =$1-100pc
• possible connection optical-UV BLR or Torus Winds

(Blustin et al. 2004, McKernan et al. 2007)

Evidence for a new, more extreme component?

• higher ionization log $\xi =$3-5 erg s$^{-1}$ cm
• higher column density $N_H =$10$^{22}$-10$^{24}$ cm$^{-2}$
• relativistic outflow velocity $v =$0.01-0.3c
• variability on short time scales (~100ks)
• location closer to SMBH $r <$0.01pc ($\lesssim 10^3 r_s$)
• accretion disk winds/ejecta? (see review Cappi 2006)
• global statistical incidence and characteristics on population?
Photoionized X-ray absorbers

Ionization parameter \( \xi = \frac{L}{nr^2} \)

- Absorbing gas is photo-ionized by central source
- Elements lighter than Fe are fully ionized
- He/H-Fe resonant absorption lines spectroscopy (4-10keV)
- All main atomic processes modeled by XSTAR code
- Direct fit of X-ray spectral data

Curve of Growth analysis

- extensive XSTAR simulations to derive Fe ion populations
- tested different input SED shapes
- direct line Voigt profile integration
- line EW as a function of:
  - Total column density \( N_H \)
  - Ionization parameter \( \xi \)
  - Gas turbulent velocity \( v_{turb} \)

(results will be published in Tombesi et al. in prep (2))
The case of Mrk509

- Bright Seyfert 1 in 2-10keV
  \((F=2-5\times10^{-11} \text{ erg s}^{-1} \text{ cm}^{-2}, L=1-3\times10^{44} \text{ erg s}^{-1})\)
- Local \((z=0.034)\)
- \(M_{\text{SMBH}}=10^8 \text{ M}_\odot \) (Peterson et al. 2004)
- 5 XMM-Newton observations (fom 2000 to 2006)

**EPIC pn data analysis:**

- Fe K band spectral analysis (4-10keV)
- Galactic absorbed power-law continuum
- neutral Fe K\(\alpha\) emission line @ 6.4 keV
- blind search for absorption lines
- visualization in contour plots
  
  (68\%, 90\%, 99\% F-test confidence contours)

**Detection probability:**

- extensive Monte Carlo simulations
- null hypothesis without absorption lines
- \(10^4\) simulated spectra for each observation
- simulated \(\Delta \chi^2\) distribution
The case of Mrk509

Results from data analysis:
- Narrow Fe resonant absorption lines in 3 obs
- Detection probability >99% F-test, >95% MC (global >99.9%)
- confirmed by MOS1-2 detectors
- variability on ~100ks time scales

Evidence of massive and relativistic outflows near SMBH!

Direct XSTAR photoionization modelling:
- $\log \xi = 5 \pm 0.4$ erg s$^{-1}$ cm
- $N_H = 2-4 \times 10^{23}$ cm$^{-2}$
- relativistic outflow $v_{\text{out}} = 0.14-0.20c$
- $v_{\text{turb}} \sim 1000$ km/s

Other outflow characteristics:
- Close to the SMBH: $r < L/(\xi N_H) = 0.007$ pc (<500 $r_s$)
- Faster than escape velocity: $v_{\text{out}} > v_{\text{exc}} = (r_s/r)^{1/2}c$ at 500 $r_s$
- High mass loss rate with injection in ISM:
  $$ M_{\text{out}} \leq 4 \left( \frac{\Omega}{4\pi} \right) M_\odot yr^{-1} $$
- Low covering factor ($\Omega$) or intermittent outflow for BH growth:
  $$ M_{\text{out}}/M_{\text{acc}} \sim 10 \left( \frac{\Omega}{4\pi} \right) $$
- Outflow/ejecta from accretion disk or part of a disk wind?
- Radiatively/magnetically driven outflows?
- Stratified X-ray warm absorbers?
Sample of radio-quiet AGNs

Statistically quantify the incidence and characteristics of highly ionized warm absorbers in a complete sample of sources.

- Selection all Seyfert 1, Seyfert 2 and NLS1 in RXTE All-Sky Slew Survey Catalog
- Cross-correlation with XMM-Newton Accepted Targets Catalog (pointed observations)
- 44 objects for 104 XMM observations
- Local ($z \leq 0.1$)
- X-ray bright ($F_{4-10\text{keV}}=10^{-12}-10^{-10} \text{ erg s}^{-1} \text{ cm}^{-2}$)

Uniform data Analysis:
- reduction and analysis of all EPIC pn spectra 4-10keV
- baseline model: Absorbed power-law + Gaussian Fe emission lines
- blind search for blue-shifted Fe absorption lines
- detailed check of instrumental background and calibration
- detection confidence level by F-test and extensive Monte Carlo simulations
Sample of radio-quiet AGNs

Preliminary results:
• 36 He/H-like Fe absorption lines detected (global confidence $\geq 99.999997\%$ !)
• 17/44 objects with blue-shifted absorption ($\geq 40\%$)
• 11/44 objects with $v_{\text{out}} \geq 0.1c$ ($\geq 25\%$)
• blue-shift velocity distribution $\sim 0$-$0.3c$, peak @ $\sim 0.1c$
• mean outflow velocity $<v_{\text{out}}>=0.103\pm0.004c$
• FeXXVI Ly$\alpha$ mean EW=$50\pm10$eV (other lines $\sim 30$eV)
  (Tombesi et al. in prep (1))

Detailed modelling and fitting:
• spectral fitting with XSTAR code
• Fe lines curve of growth analysis
• absorber parameters: $N_H$, $\xi$, $r$, $v_{\text{out}}$
• estimate of global mass loss rate, acc/ejection, …
  (in companion paper Tombesi et al. in prep (2))
Conclusion

• Evidence for unknown relativistic and massive outflows close to SMBH
• Common from X-ray observations
• Radiatively/magnetically driven accretion disk winds/ejecta?
• Connection with radio jets (in Radio Loud objects)?
• Important for AGN and accretion physics
• Indications for X-ray emission/location
• Influence on SMBH growth?
• Contribution to feedback SMBH and host galaxy (e.g. $M_{\text{BH}}$-$\sigma$ relation)

Future developments: study of variability; observations from other X-ray satellites (Chandra, Suzaku); connection with soft X-ray warm absorbers; ...
Thank you