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

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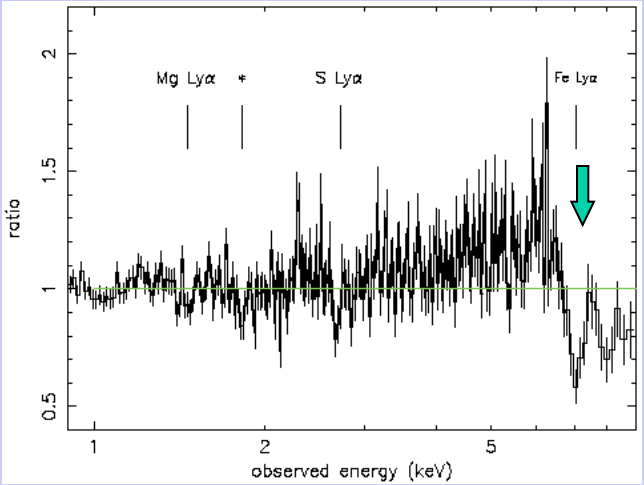
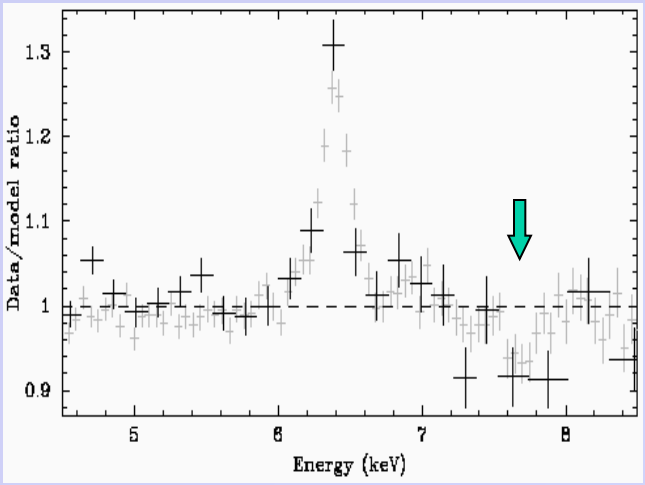
X-ray evidence

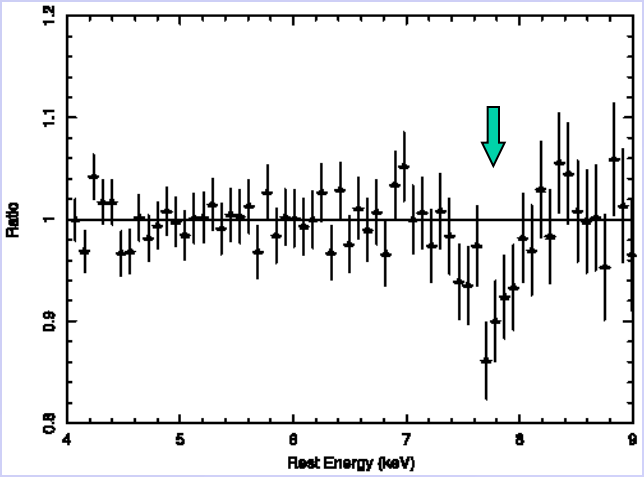
Narrow absorption lines at E>6keV detected in the X-ray spectra of several Radio-Quiet AGNs (e.g. Pounds et al. 2003; Reeves et al. 2004; Dadina et al. 2005; Markowitz et al. 2006; Braito et al. 2007; Turner et al. 2008; Cappi et al. 2009; ...)



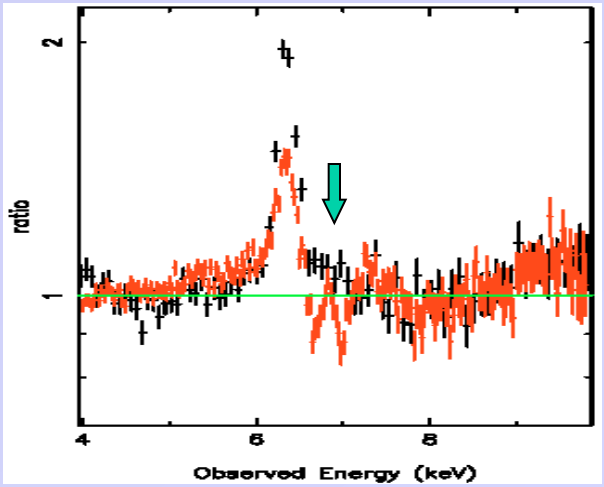
PG1211+143 (Pounds et al. 2003; Pounds & Page 2006)



IC4329A (Markowitz et al. 2006)



MCG-5-23-16 (Braito et al. 2007)



NGC3516 (Turner et al. 2008)

General characteristics

Presence of previously unknown ultra-fast outflow:

- Blue-shifted FeXXV/XXVI K resonant absorption
- Highly ionized ($\log\xi \approx 2$-5 erg s^{-1} cm)
- Large column densities ($N_H \approx 10^{22\text{-}24}$ cm^{-2})
- Large outflow velocities (up to 0.2-0.4c)
- Variability on short time-scales (down to ≈100ks)
- Location close to SMBH (r<0.01pc, <10^3 r_g)

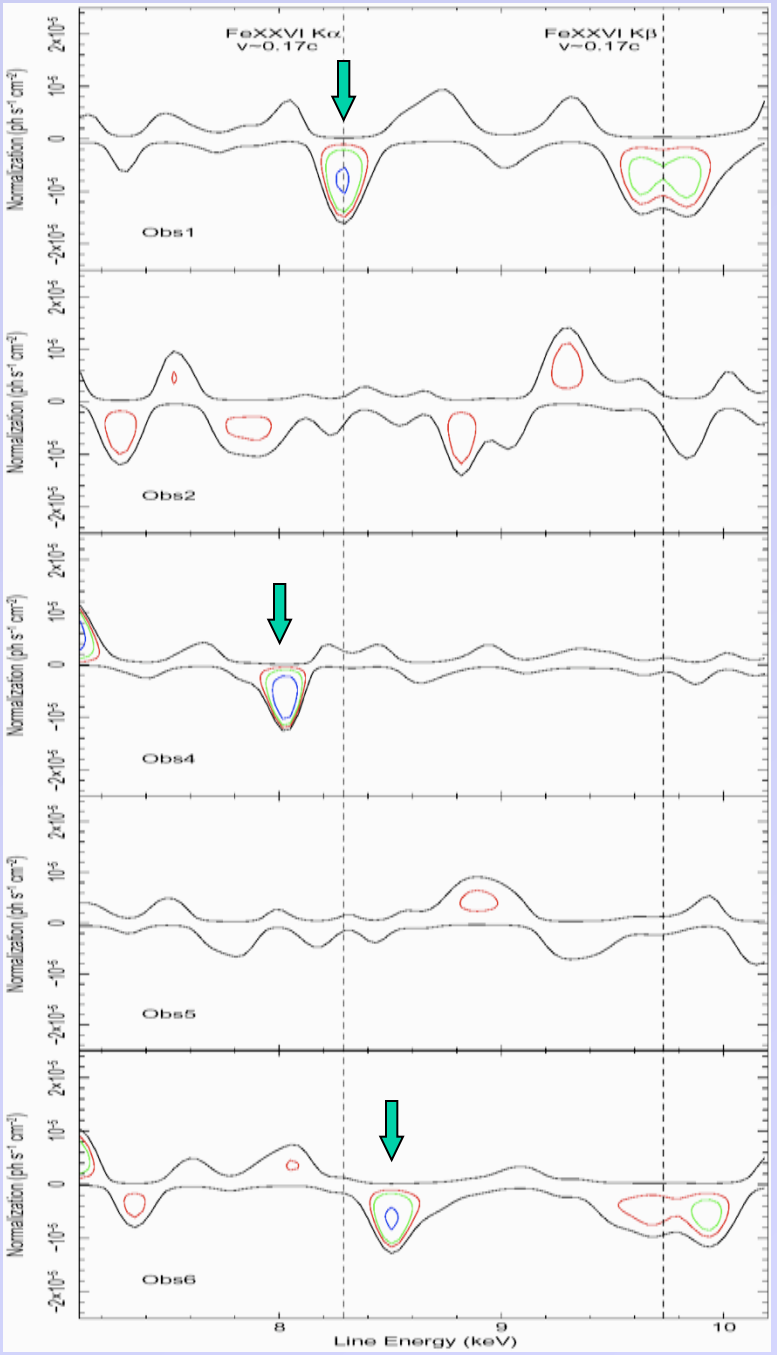
Different from classical X-ray Warm Absorbers?

- ~50% Seyfert galaxies in soft X-rays
- Lower ionization ($\log\xi$=0-3 erg s^{-1} cm)
- Lower column densities ($N_H = 10^{20\text{-}23}$ cm^{-2})
- Slow outflow velocities (≈1000 km/s)
- More distant (r≈1-100pc)
- Connection with optical-UV BLR or torus winds

(e.g. Blustin et al. 2004; McKernan et al. 2007)

Publication bias? (Vaughan & Uttley 2008)

- Significance of individual blue-shifted line can be weak
- Only positive detections are reported in literature
- Doubts on lines global significance



MRK509 contour plots (Cappi et al. 2009)

Fast outflows in AGNs

• Fast outflows are well known to be present in some AGN classes (e.g. relativistic jets in radio-loud AGNs; BAL-QSOs)

• Fast and massive outflows are naturally generated by black hole accretion systems. Accretion disk winds/ ejecta? (e.g. Proga et al. 2000; King & Pounds 2003; Schurch et al. 2009; Ohsuga et al. 2009)

• Need to establish global frequency and characteristics of fast outflows in radio-quiet AGNs

Physical implications: (e.g Cappi 2006)

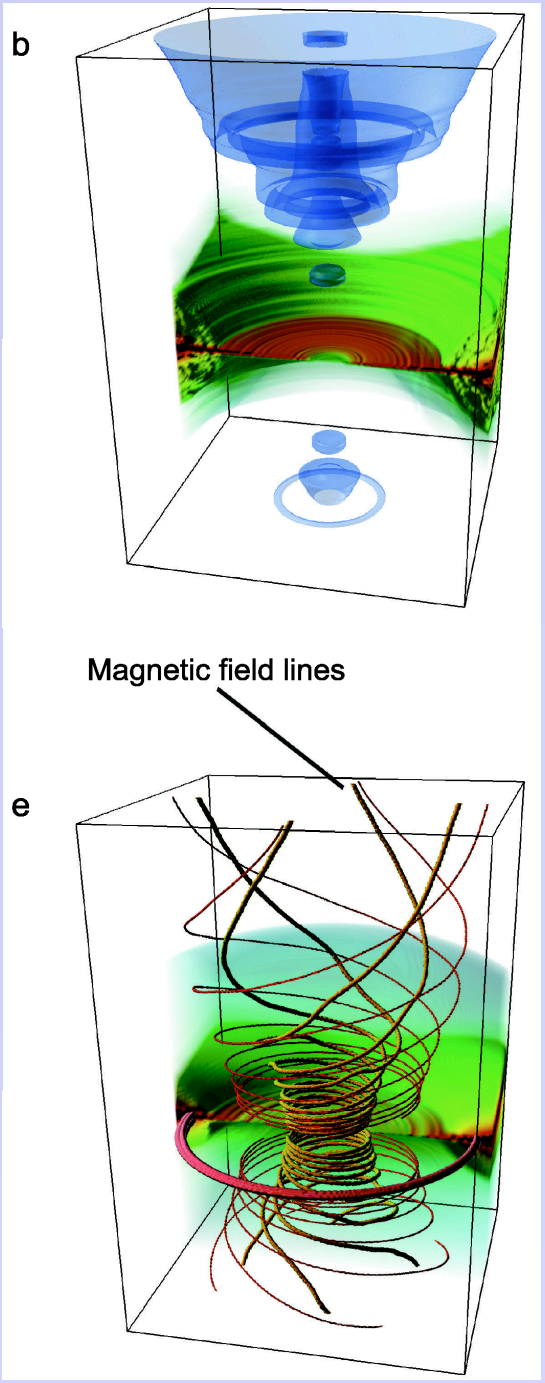
• insights into black hole accretion physics

• growth of SMBHs

• AGN feedback and evolution of the host galaxy

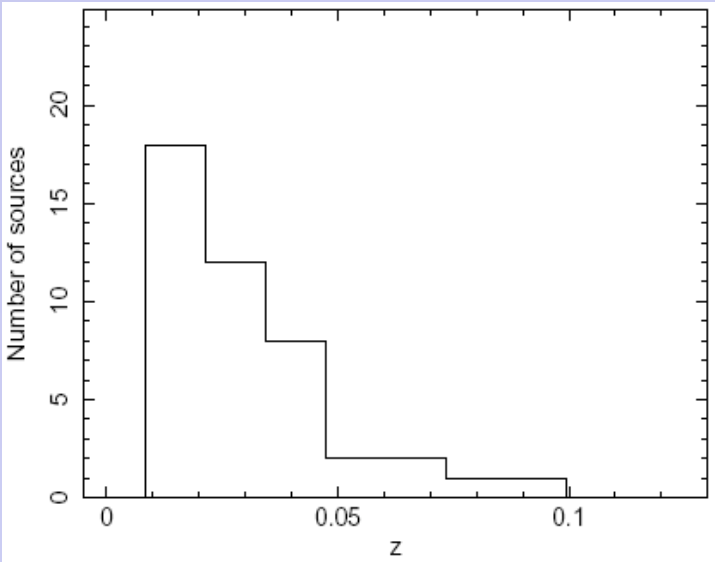
Aim of our work:

Statistically quantify the incidence and parameters of blue-shifted Fe K absorption lines in a complete sample of radio-quiet AGNs

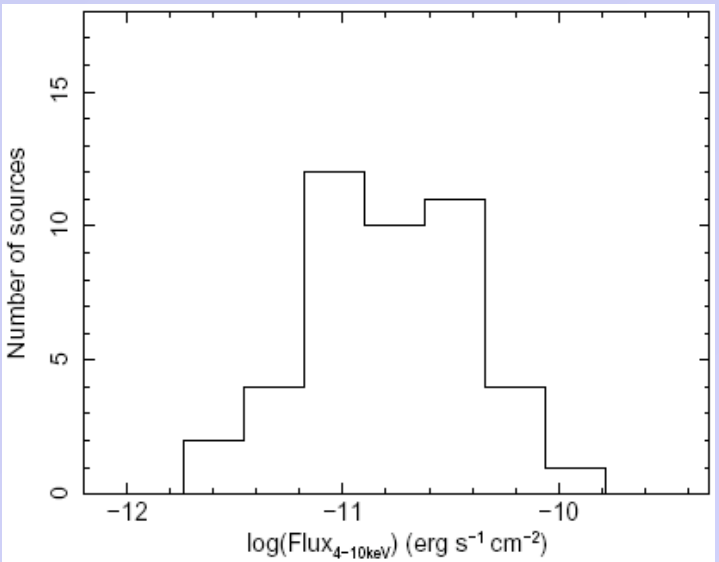


(Ohsuga et al. 2009)

Sample of radio-quiet AGNs



Cosmological red-shifts of sources
(Tombesi et al. in prep I)



4-10keV flux of sources
(Tombesi et al. in prep I)

- Selection of all NLSy1, Sy1 and Sy2 in RXTE All-Sky Slew Survey Catalog (complete at 90% at 4σ limiting flux 10^{-11} erg s^{-1} cm^{-2} in 4-10keV; Revnivtsev et al. 2004)
- Cross-correlation with XMM-Newton Accepted Targets Catalog
- 44 objects for 104 pointed XMM-Newton observations
- Local ($z \leq 0.1$)
- X-ray bright ($F_{4\text{-}10keV}=10^{-12}$-$10^{-10}$ erg s^{-1} cm^{-2})

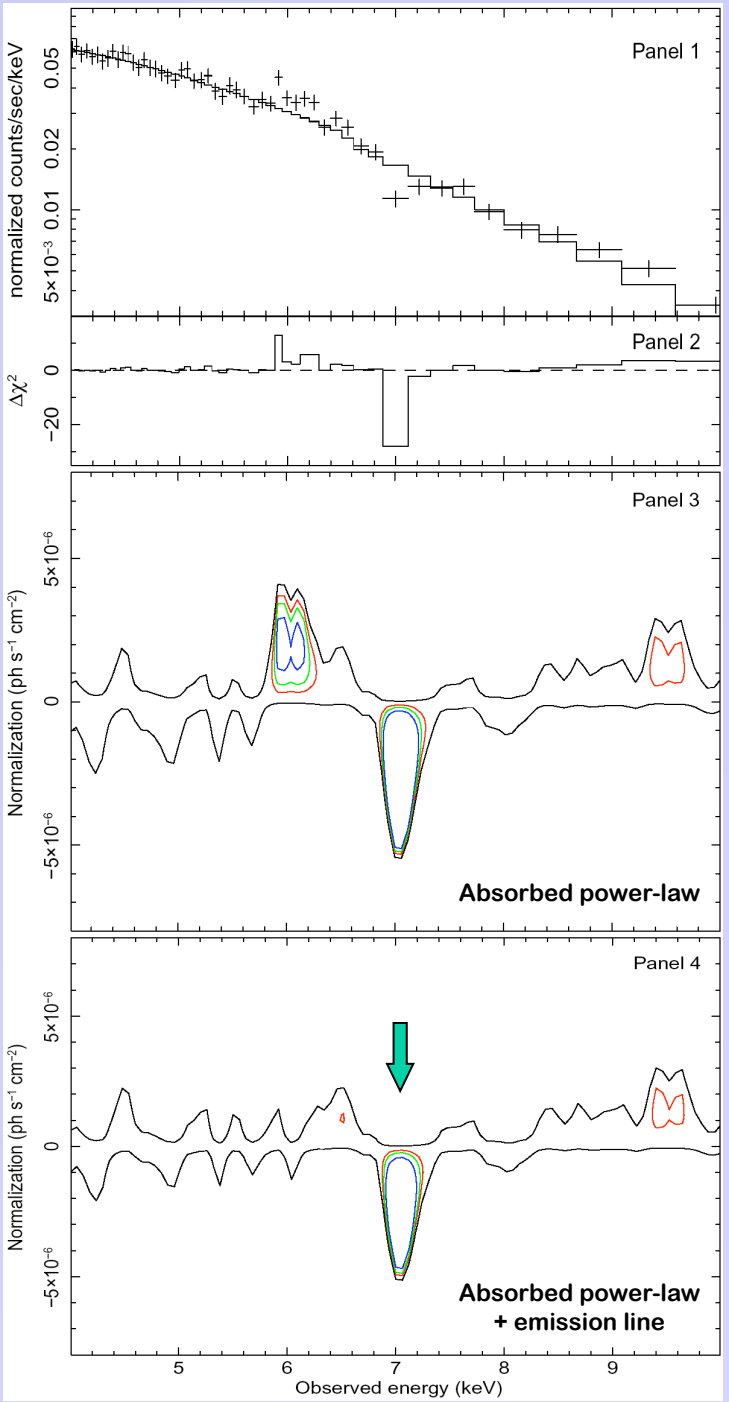
Absorption lines search

Uniform spectral analysis:

- Reduction and analysis of all EPIC pn spectra in the 4-10keV
- Baseline model: absorbed power-law + Gaussian Fe K emission lines

Absorption lines search:

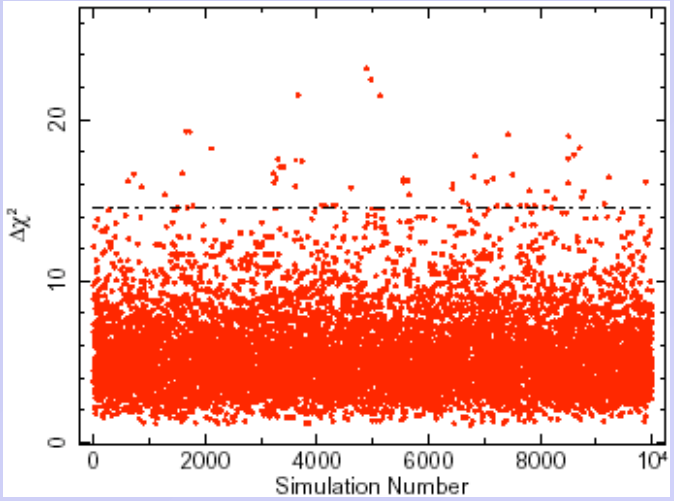
- Addition of narrow line to baseline model stepping energy in 4-10keV and recording $\Delta\chi^2$ deviations
- Visualization on energy-intensity contour plot (significance 68% red, 90% green, 99% blue) (e.g. Cappi et al. 2009)
- Selection of narrow lines with F-test confidence levels ≥99%
- Line parameters determined by direct fitting to the data



Example of PG1211+143
(Tombesi et al. in prep I)

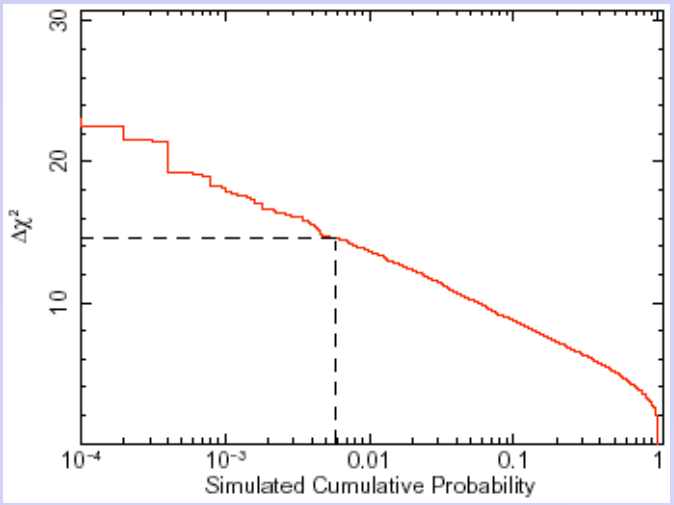
Absorption lines significance

F-test can overestimate the detection significance for a blind search of emission/absorption lines over a range of energies (e.g. Protassov et al. 2002).



Extensive Monte Carlo simulations (e.g. Cappi et al. 2009)

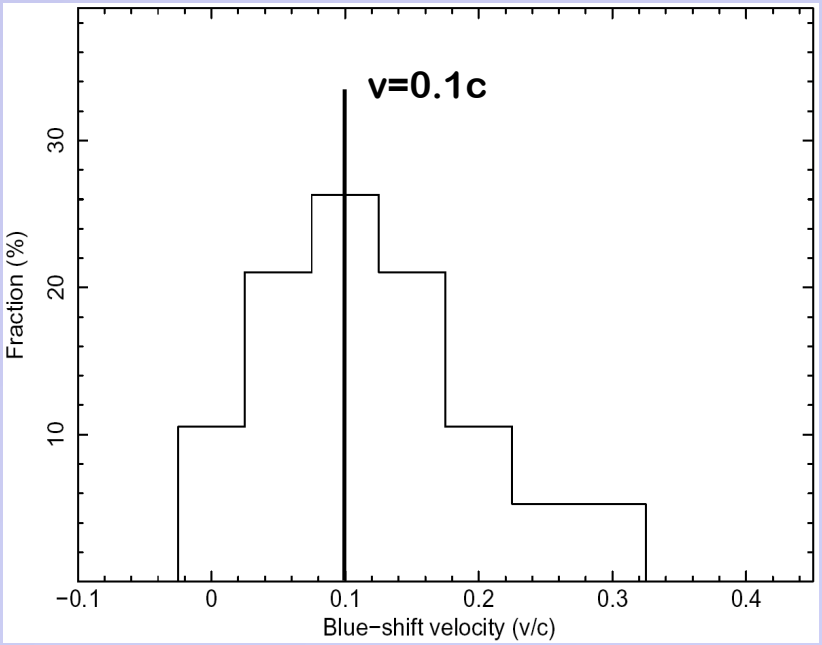
- Additional significance test for lines at energies ≥7.1keV
- Null hypothesis that spectra are fitted by model without absorption lines
- 10^3 simulated spectra for each case
- Simulated $\Delta\chi^2$ distribution for random generated lines
- Selection of lines with MC confidence levels ≥95%
- 36 absorption lines detected (22 at E≥7.1keV)



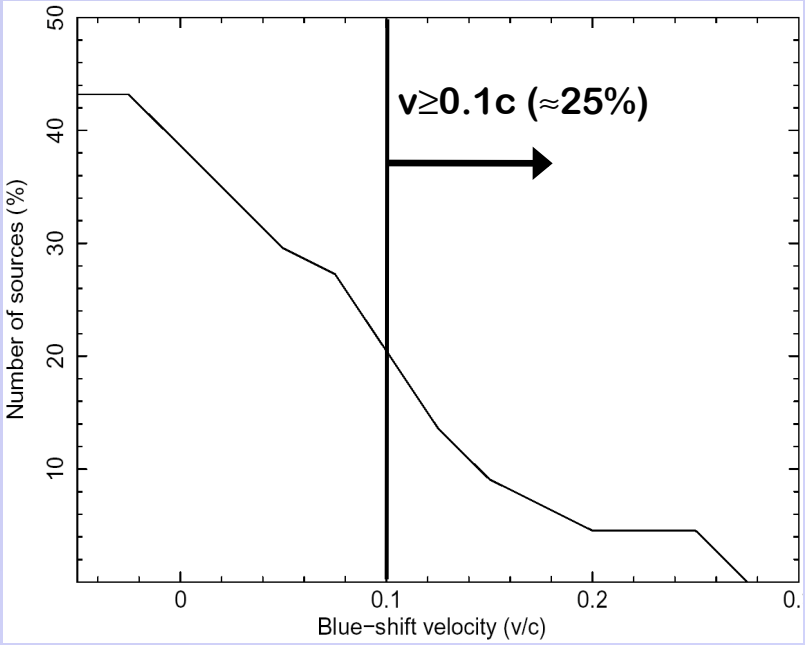
Global probability to be generated by random fluctuations is very low ($\leq 10^{-8}$ from Binomial distribution).

- Checked no contamination from pn background and calibration
- Independent confirmation of blue-shifted lines detection from MOS data (without relying on any statistical method)

Results



Blue-shift velocity distribution (Tombesi et al. in prep I)



Cumulative velocity distribution (Tombesi et al. in prep I)

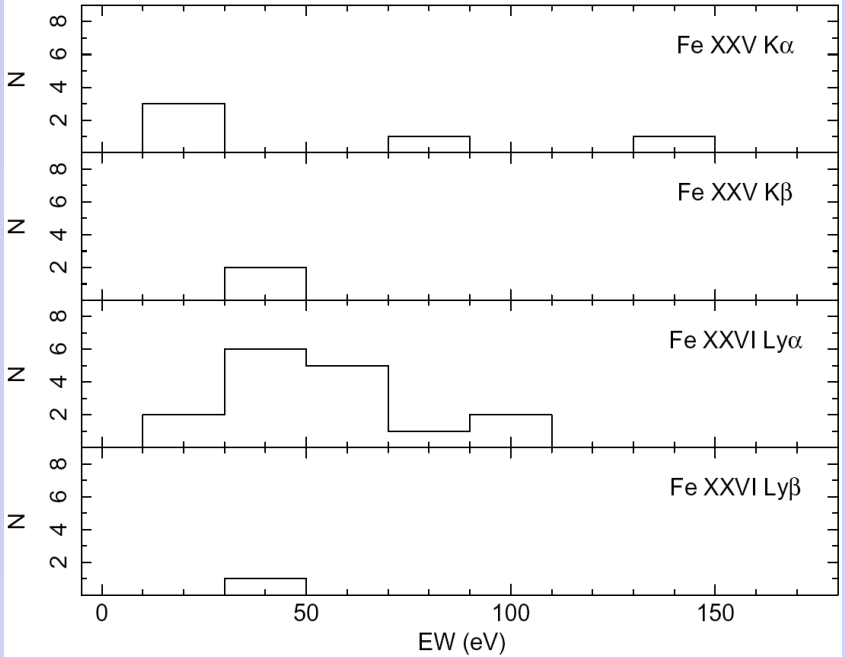
- **Identified with FeXXV and FeXXVI K-shell resonant absorption**
- **19/44 objects with absorption lines (≈43%)**
- **17/44 objects with blue-shifted absorption lines (lower limit ≈39%, can reach a maximum of ≈60%)**
- **11/44 objects with outflow velocity ≥0.1c (≈25%)**
- **Blue-shift velocity distribution ~0-0.3c, peak ~0.1c**
- **Average outflow velocity <v>=0.110±0.004c**

(Tombesi et al. in prep I)

Results

Line	Num (A)	EW (A) (eV)	Num (B)	EW (B) (eV)
Fe XXV Kα	4	32 ± 7	1	130 ± 35
Fe XXV Kβ	2	29 ± 9	0	...
Fe XXVI Lyα	8	43 ± 8	8	45 ± 11
Fe XXVI Lyβ	1	34 ± 9	0	...

Average line EWs. (A) v<0.1c (B) v≥0.1c (Tombesi et al. in prep I)

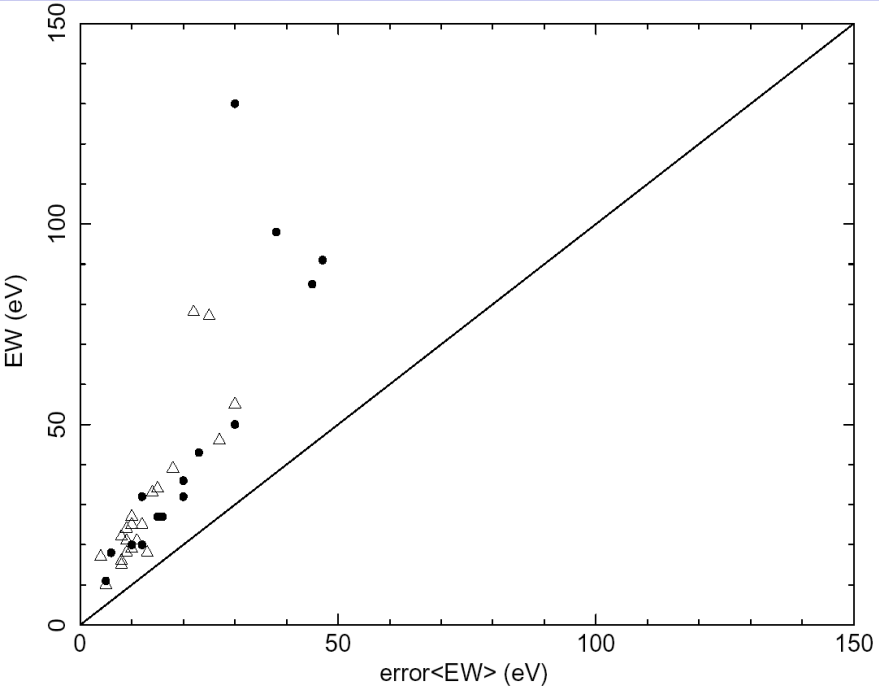


Line EWs distribution(Tombesi et al. in prep I)

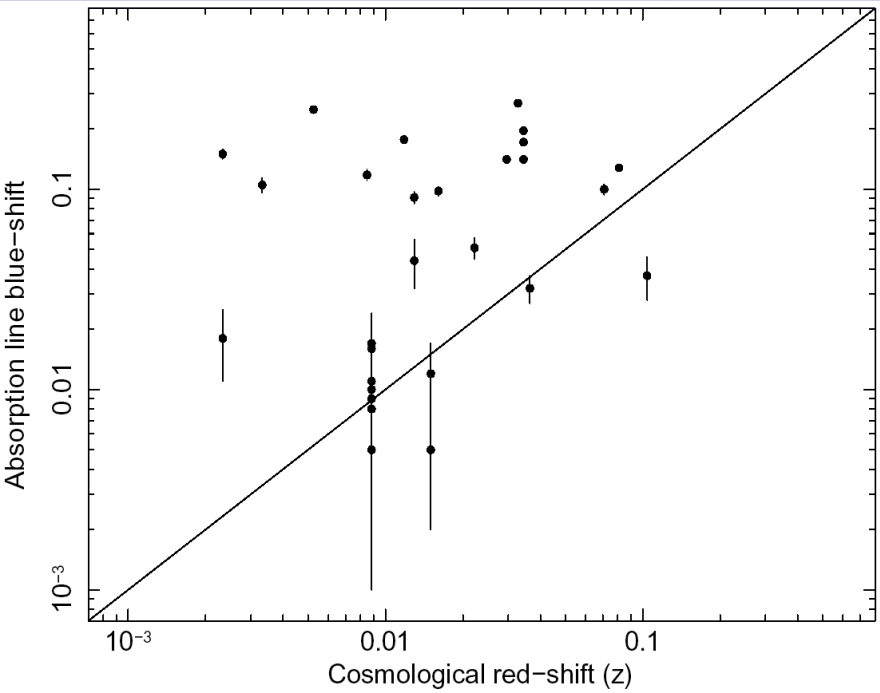
- **Most frequent detected line is FeXXVI Lyα**
- **EW is in the range ≈10-100eV, with mean ≈40-50eV**
- **Estimeted global covering factor from fraction of sources with lines (C=Ω/4Π)≈0.4-0.6**
- **Geometry not very collimated, large opening angles favored**

(Tombesi et al. in prep I)

Discussion



Blue-shifted line EWs vs. 90% error (Tombesi et al. in prep I)



Blue-shift vs. cosmological red-shift (Tombesi et al. in prep I)

Publication bias solved:

- Uniform analysis on complete sample of sources
- Lines detection assessed by MC simulations
- Global random probability very low ($\leq 10^{-8}$)
- Detection independently confirmed by MOS data

(Tombesi et al. in prep I)

No correlation between cosmological red-shift and lines blue-shift, no systematic local ($z \approx 0$) absorption.

(Tombesi et al. in prep I)

Physical modelling

Line			<E>	<f>
Fe XXV Kα	$1s^2$–1s2p	i+r	6697 eV	7.7×10^{-1}
Fe XXV Kβ	$1s^2$–1s3p	i+r	7880 eV	1.55×10^{-1}
Fe XXVI Lyα	1s–2p	1 + 2	6966 eV	4.2×10^{-1}
Fe XXVI Lyβ	1s–3p	1 + 2	8250 eV	8.0×10^{-2}

Data modelling

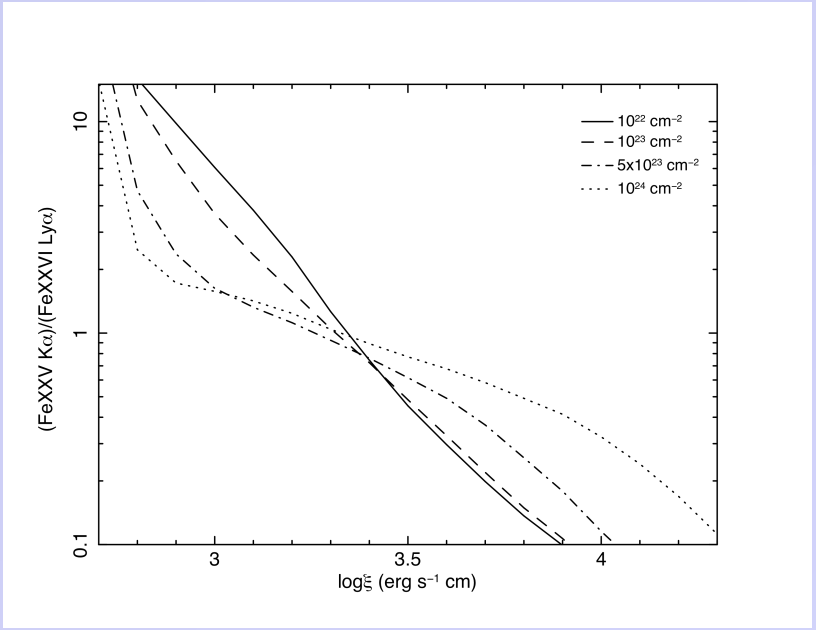
- Photoionized absorbers modeled with XSTAR
- Direct pn spectral data fitting (in the 4-10keV band)

Curve of Growth analysis

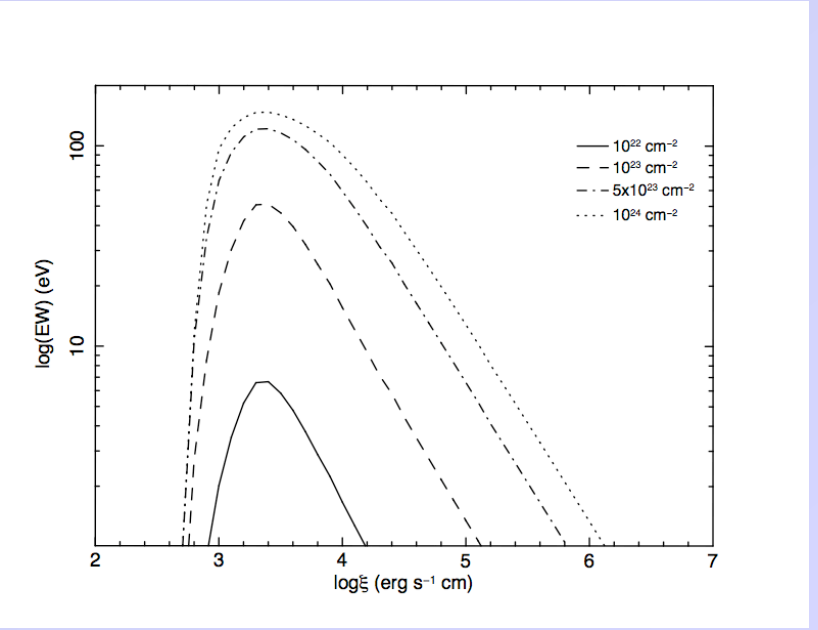
- XSTAR simulations to derive Fe ions populations
- Tested different input SED shapes
- Direct line Voigt profile integration
- Line EW as a function of:
  - Total column density N_H
  - Ionization parameter ξ
  - Gas turbulent velocity v_{turb}

This will allow to estimate physical parameters, such as: r, M_{out}, M_{acc},…

(results will be published in Tombesi et al. in prep II)



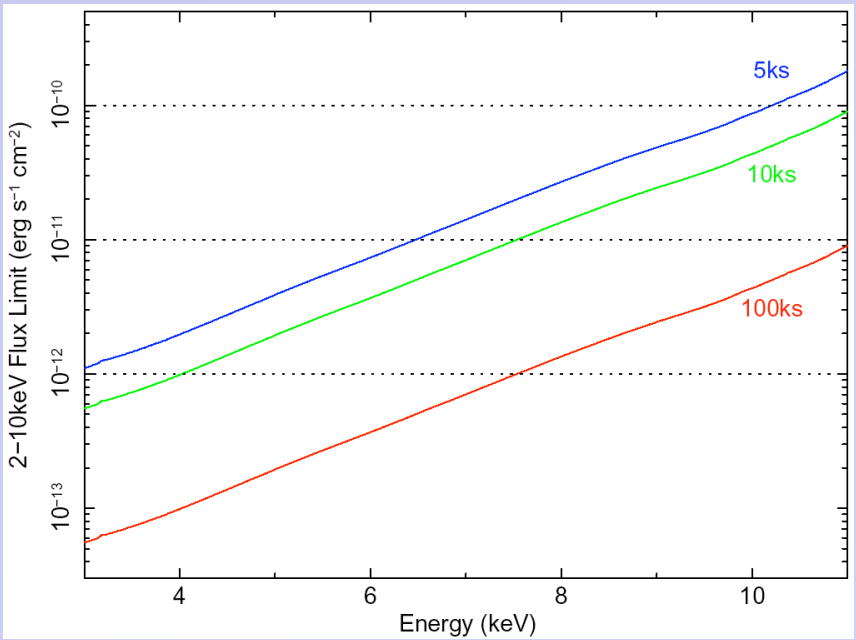
FeXXV Kα/FeXXVI Lyα ratio (Tombesi et al. in prep II)



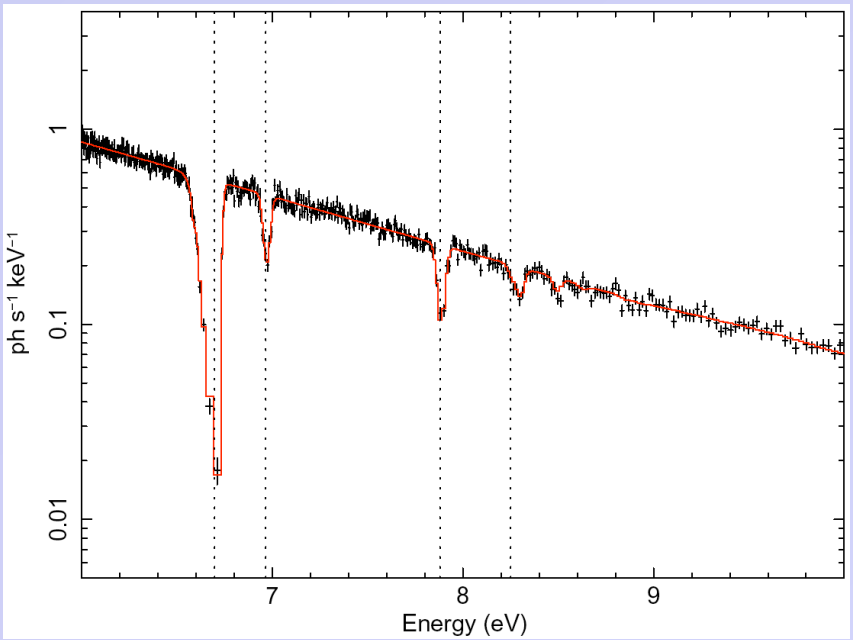
Curve of Growth FeXXVI Lyα (Tombesi et al. in prep II)

IXO calorimeter simulations

X-ray Microcalorimeter Spectrometer (XMS): high effective area (≈0.65m² @ 6keV) and high energy resolution (FWHM≈2.5eV) from 0.1keV up to 12-13keV.



Flux limits (EW=10eV) (Tombesi et al. in prep III)



logξ=3 erg s^{-1} cm, N_H=10^{23}cm^{-2}, b=1000km/s (Tombesi et al. in prep III)

Flux limits

- 2-10keV flux limits for 5σ detection of narrow absorption lines in the 3-11keV
- Different EWs, exposure times and responses
- Lines of EW=10eV (50eV) in ≈6-9keV for ≈10^{-12} (10^{-13}) erg s^{-1} cm^{-2} (expo 100ks)
- Spectral variability on time-scales of 5 (10) ks for ≈10^{-11} (10^{-12}) erg s^{-1} cm^{-2}

Spectra simulations

- Simulations of highly ionized and massive absorbers
- FeXXV/XXVI K lines detectable with high significance
- Line details (profile, energy, broadening) measured with high accuracy
- Extend study to less bright sources
- Possible detection of lines with higher blue-shifts

Conclusions

- Search for narrow blue-shifted Fe K absorption lines in a complete sample of 44 radio-quiet AGNs observed with XMM-Newton
- 36 detected absorption lines (22 at E≥7.1keV)
- Global veracity is strong and publication bias solved

Existence of highly ionized, massive and ultra-fast outflows in radio-quiet AGNs:

- ≈40% of sources have blue-shifted absorption lines (≈25% with v≥0.1c)
- Outflow velocities up to relativistic values (≈0.2-0.3c)
- Global covering factor ≈0.4-0.6, large opening angles favored
- Important for: BH accretion physics, AGN feedback with host galaxy, SMBH growth, …
- Improvement expected from future X-ray missions, such as Astro-H and IXO

Thank you