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Distant and disk reflection in the average X-ray spectrum of AGN in the Véron-Cetty-Véron catalogue

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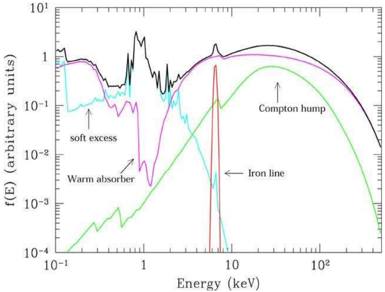
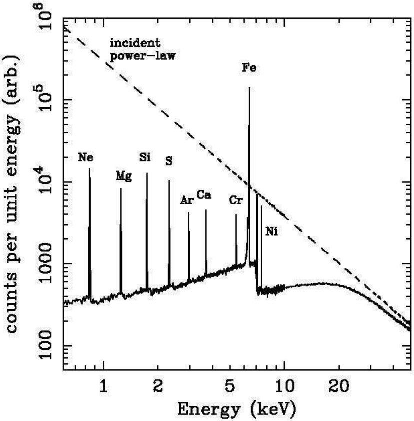
X-ray spectra of AGN (Figure: Risaliti et al. 2004)

- **X-ray continuum**: IC scattering of the primary thermal emission in a hot corona.
- **Absorption**: from neutral and ionised material
- **Reprocessing**: fluorescence and Compton reflection (in the disk or further away, e.g. in the torus)



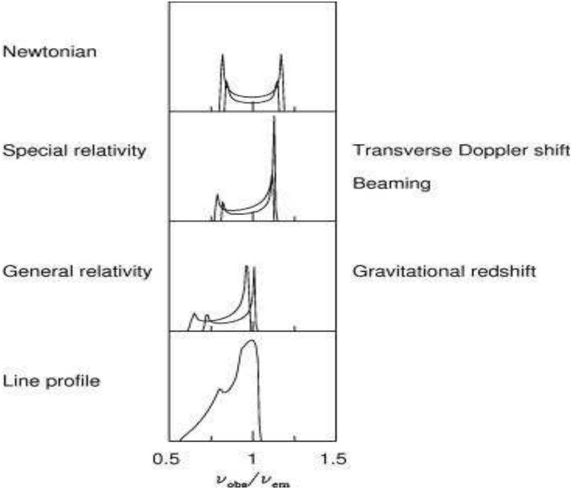
Reprocessing of the primary radiation in neutral material

- Compton scattering: E>10 keV
- Photoelectric absorption: E<10 keV. Photoionisation can be followed by de-excitation and fluorescence.
- The most prominent line is the iron K_α line at 6.4 keV, important to probe the central engine of AGN



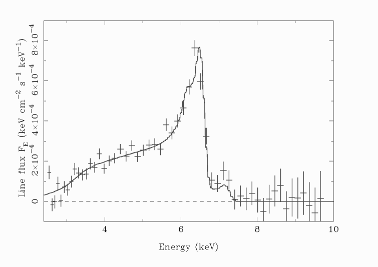
(Figure from Reynolds et al. 1995)

Expected iron lines from the innermost regions of accretion disks: Fabian et al. 1989



Iron lines in individual bright AGN (figure: Fabian et al. 2002)

- The line of MGC-6-30-15 observed by `XMM-Newton`: intense narrow core and prominent red wing . Their detection is useful to explore:
  - environment far from the central SMBH
  - environment close to the central SMBH
- The incidence of both components is still unclear for most AGN



Stacking of iron lines: motivation

- The detection of the broad iron lines is only possible in high Signal-to-noise-ratio (**SNR**) spectra (Guainazzi et al 2006, Nandra et al. 2007, de la Calle et al. 2010)
- Such spectral quality in observations of distant AGN is rather difficult to be reached with the current facilities
- Statistical approaches computing the average (or the sum) can offer the preview of what will be obtained with future instruments

Previous X-ray stacking: evidence for broad Fe lines

- Broad iron line detected in Seyferts observed with ASCA and in their average (Nandra et al. 1997)
- Broad iron line detected in the *XMM-Newton* LH field (Streblyanska et al. 2005)

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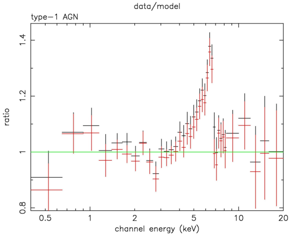

Previous X-ray stacking: tantalising evidence for broad Fe lines

- Tantalising evidence for broad iron lines in the Chandra deep fields 1 Ms (Brusa et al. 2005; Civano et al. 2005)
- Tantalising evidence ($\sim 2\sigma$) for a broad iron line in one subsample of the 2 Ms Chandra deep Fields including AEGIS (Falocco et al. 2012)
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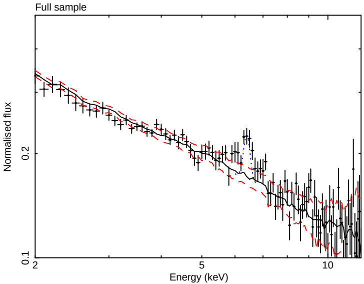
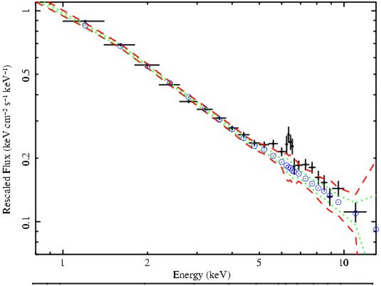


Previous X-ray stacking: evidence for narrow Fe lines (not excluding the broad components)

- Narrow iron lines in the high redshift AGN of the XMS-XWAS catalogue



(Corral et al. 2008)

- Narrow iron lines in the XBS sample of higher luminosities (Corral et al. 2011)
- Narrow iron lines in the 2XMM catalogue (Chaudhary et al. 2010, 2012)
- Ionized iron line in the deep XMM-COSMOS sample (Iwasawa et al. 2012)

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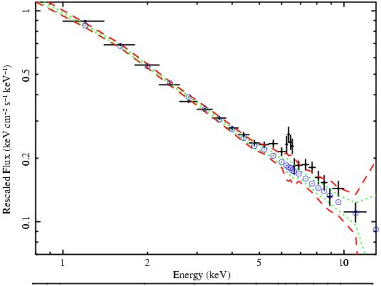

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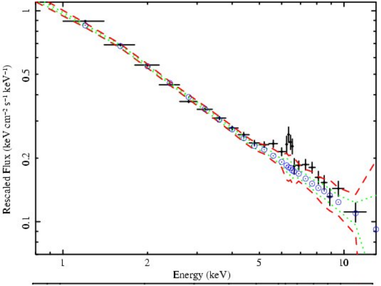

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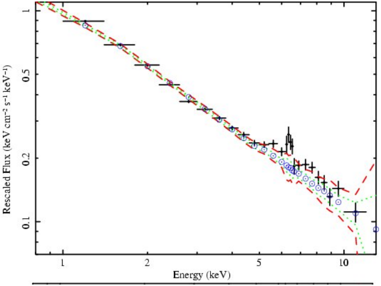

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Motivation for this work

The ultimate purpose of this work is to investigate:

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Sample selection

- Cross-correlate the **2XMM** (Watson et al. 2008) and the **Véron-Cetty-Véron** (Véron-Cetty and Véron 2006 and 2010) catalogue
- Select spectra of **high quality**: with signal-to-noise-ratio SNR>15
- Select unabsorbed AGN ($\log(\mathrm{N_H}) < 21.5$)
- Select sources with Γ (90%) higher than 1
- 263 AGN (388 EPIC spectra)

Properties of the sample: distribution in L-z plane

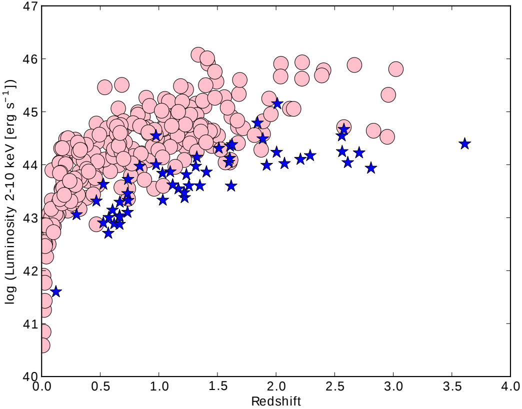

Figure: Pink: current sample. Blue: XMM-CDFS studied in Falocco et al. 2013

Treatment of the single spectra (Corral et al. 2008)

- **Fit** each binned spectrum in 1-12 keV restframe (fix Galactic $\mathrm{N_H}$, free intrinsic $\mathrm{N_H}$, Γ and normalisation, using χ^2 statistics)
- **Correct for detector response** each unbinned spectrum, then for **Galactic absorption**, then for **redshift**
- **Normalise** with continuum
- **Bin** in order to have 0.1 keV bins

Averaging of the spectra and their analysis

- **Average** in the standard way (non-weighted average)
- Extract the spectral properties of AGN from the average observed spectra and using two sets of simulations:
  1. continuum simulations to be compared with the observed data
  2. unresolved line simulations, to estimate the spectral dispersion and consider it in the spectral fitting

Simulations set 1: continuum

110 **simulations** of each source of the best fit continuum model:

- Apply the same treatment to the simulated samples
- Obtain 110 average simulated spectra
- Use their median to represent the simulated continuum
- Estimate the line EW using the simulations

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Simulations set 2: unresolved lines

The X-ray instruments and the method can broaden narrow lines. To characterize this effect:

- 1 simulation for each source of a **high-SNR unresolved line** at a certain E
- Repeat the simulation for different centroid energies
- Apply the same averaging method to each simulated sample
- Obtain an average simulated line for each E
- Estimate Σ_{method} at each E, and study the trend $\Rightarrow$ $\Sigma_{method}(E) = 96(\frac{E}{6keV})^{0.401}$ eV
- Take into account the obtained $\Sigma_{method}(E)$ in the spectral fitting convolving the models with a gaussian smoothing

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Results

The average spectrum and model-independent study of the iron line

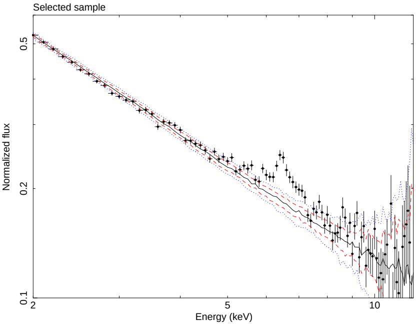

Figure: The model-independent estimate of the EW is 95±9 eV for a line centred at 6.4 keV and broad 0.4 keV.

Fits with distant reprocessing

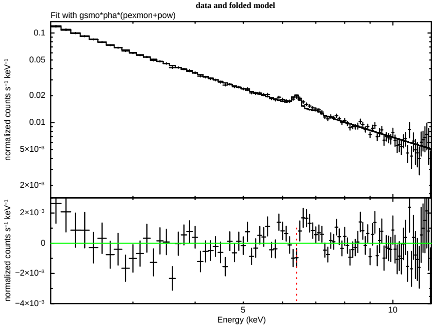

Figure: Average spectrum fitted to reprocessing in distant material (R=0.46±0.07). χ^2=144.5/96.

Fits with distant and disk reprocessing

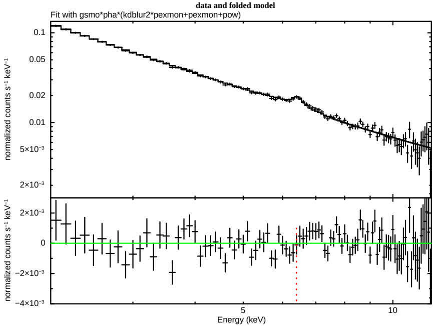

Figure: Reprocessing in distant and disk material. Disk component significant at 6.5 σ. Reflection factors (contribution of each component): $R_{non-rel}$=0.25$\pm$0.09 and R_{disk}=0.65$\pm$0.10. χ^2=111.8/95.

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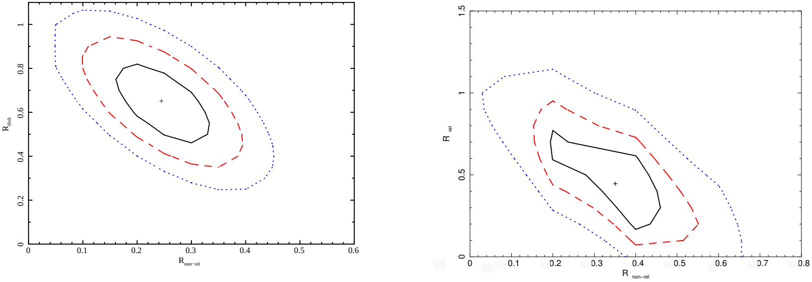

Figure: 1, 2, 3 σ contours of the reflection factors in the present work (left) and in our previous work (right, Falocco et al. 2013)

Fits with ionisation

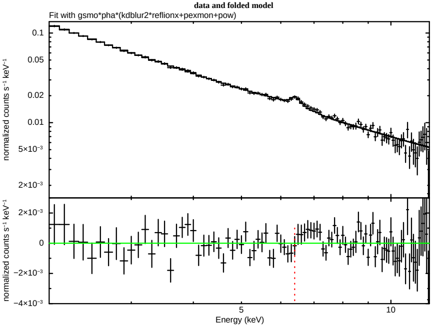

Figure: Ionisation factor (< 58 erg cm s^{-1}) includes also the non-ionised case. χ^2=113.7/94

Overall Conclusions

- we detected distant reflection
- the addition of disk reflection is required at 6.5 σ
- we do not find evidence for a significant ionisation of the accretion disk

The paper has been accepted for A&A

Future work

- combine shallow and deep X-ray surveys to investigate the average spectra in bins of luminosity and redshift
- apply the method to new catalogues (e.g. the 3XMM)
- On longer timescales: study individual spectra of AGN with future facilities (e.g. Athena)

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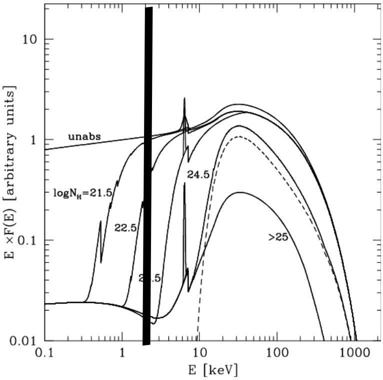
X-ray spectra of AGN with different $\mathrm{N_H}$ (Figure: Gilli et al. 2007)

- $N_{\mathrm{H}} \lesssim 10^{21.5}\mathrm{cm}^{-2}$ (low optical absorption, Caccianiga et al. 2007): negligible continuum suppression (E>2 keV)
- $N_{\mathrm{H}} > 10^{21.5}\mathrm{cm}^{-2}$: absorption in X-rays



Assessment of our method

- Checked that the correction for detector response has no effect of distortion of the spectra
- Checked the best continuum calculation to normalise the spectra (2-5 keV in this work)
- Demonstrated the robustness of our results using different ways to compute the average (average with and without sigma clipping, median)
- Check results with different binning and error calculation
- Compute the average for MOS and pn spectra separately