IFCA (UC-CSIC)

# Relativistic echoes from the distant Universe: Fe lines in the XMM CDFS

Serena Falocco
Francisco Carrera

May 31, 2012

A. Corral, X. Barcons, A. Comastri, R. Gilli, P. Ranalli, C. Vignali, N. Cappelluti, K. Iwasawa, M. Rovilos, I. Georgantopulous

# How common are the broad iron lines?

- In single high SNR observations: relativistic lines are detected at least in few AGN (e.g. Fabian+2002)
- Using averaging/stacking methods: the broad line population is statistically significant (e.g. Nandra+97, Brusa+2005, Streblyanska+2005)
- With similar methods applied to other samples: broad lines are not statistically significant (e.g. Corral+2008, Chaudhary+2010, Chaudhary+2012)
- With similar methods recently applied to deep fields: ionized lines are significant (Iwasawa+2012) Broad symmetrical lines are the composition of narrow neutral and ionized lines, with a hint of a relativistic contribution (Iwasawa+2012, Falocco+2012)

# Selection of the sample

- Select sources with secure spectroscopic redshifts
- Select the 100 spectra with the best SNR (181623 counts in 2-12 keV rest-frame)
- Define Absorbed ($log(N_{\mathrm{H}}) > 21.5$ with 50240 counts) and Unabsorbed sample ($log(N_{\mathrm{H}}) < 21.5$ with 131383 counts)
- Define three bins in luminosity (with thresholds log(L)=43.70 and log(L)=44.22, with L in erg/s) and three bins in redshift (with thresholds z=0.837 and z=1.605)

# Characteristics of the sample

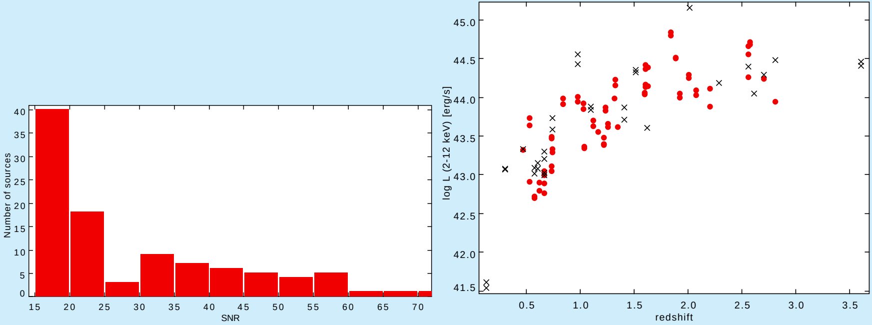



Figure: Left-hand panel: SNR distribution of the sample; right-hand panel: distribution of Unabsorbed and **Absorbed** sources in the parameters space

# Method of analysis (Corral et al. 2008, Corral et al. 2010, Falocco et al. 2012)

- Fit with fix Galactic Nh, free intrinsic Nh in 2-12 keV restframe, $\Gamma$, normalisation
- Correction for detector response
- Corrections for Galactic absorption
- De-redshift
- Normalize with continuum between 2- 5 keV and 8-10 keV restframe
- Binning (using 25 bins)
- Average in the standard way

# Characterization of continuum and narrow features using the simulations

- 110 simulations of each source using the best fit continuum model: after applying our method, we obtained 110 average simulated spectra (and we use the their median to represent the simulated continuum)
- 1 simulation of each source of high-SNR unresolved lines centered at several E (1-10 keV). => $\sigma_{method}$ as a function of E. For the full samples, we obtained:
  - $\alpha = 0.32$ (slope of the $\sigma(E)$ powerlaw)
  - $\sigma_{method} = 113$ eV at 6.4 keV
  - $\sigma_{method} = 117$ eV at 6.9 keV

# Spectrum from MOS+PN

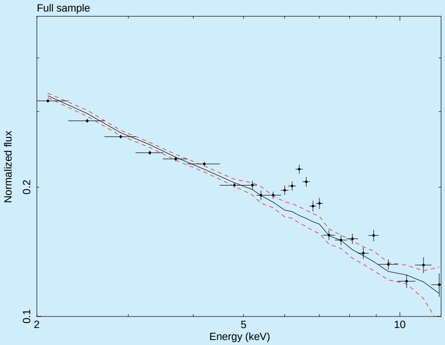



Figure: Averaged spectrum of the full sample with simulated continuum and 1 sigma confidence levels.

# Absorbed and unabsorbed sample

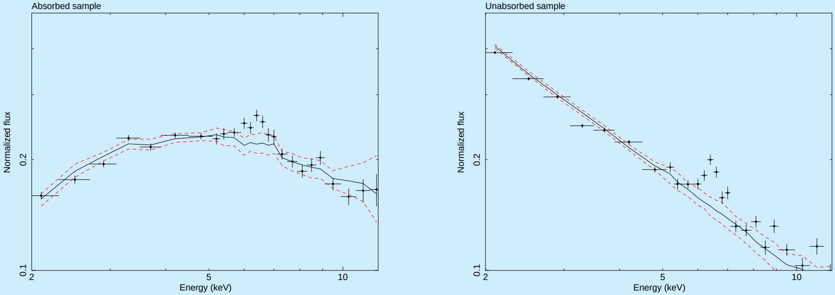



Figure: Absorbed (left) and unabsorbed (right) sample.

# Low-L and middle-L bins

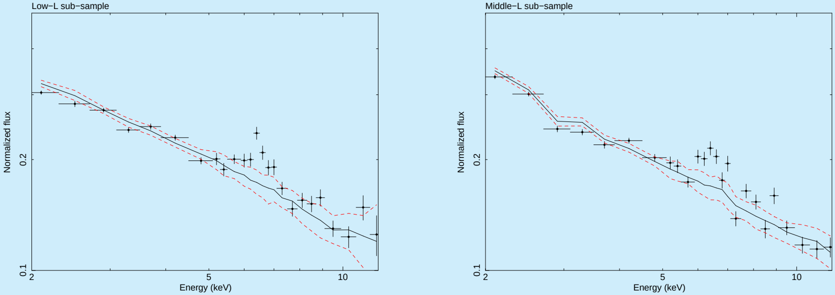
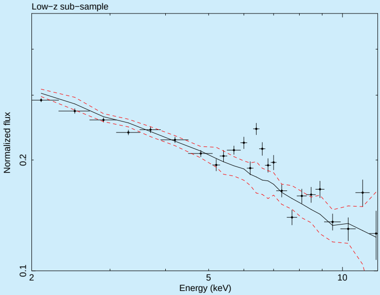



Figure: Low-L (left) and middle-L (right) sample.

# Low-z and middle-z bins



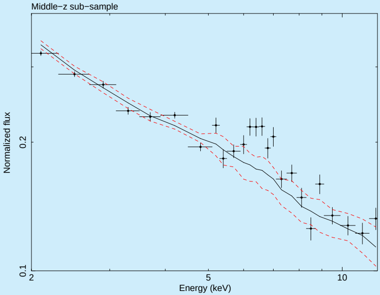




Figure: In low-z (left), the low bin at 6.2 keV, for probable instrumental problems, affects our detection of the broad line

# High-z and high-L subsample

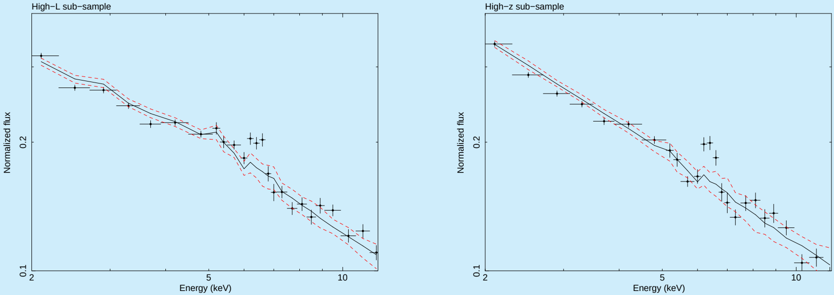



Figure: In high-L (left) and high-z (right) subsamples, probable instrumental problems affect our detection of the Fe line

# Model-independent estimation of the Iron line significance and EW using the simulations, results

- Significance (fraction of average simulated spectra with a lower flux than the average observed spectrum)= 1 (6.2-6.6 keV) in the full sample and its subsamples
- EW$\sim 2\delta \sum_{E-\delta}^{E+\delta} \frac{T(E)-C(E)}{C(E)}$ estimated for each simulated sample using, as T(E), the average observed spectrum and, as C(E), the average simulated spectrum
    - Full: EW=$129^{+17}_{-19}$ eV
    - Unabsorbed sample: EW=$157^{+29}_{-24}$ eV
    - Absorbed sample: EW=$86^{+31}_{-22}$ eV

# Analysis of the Iron line using Xspec, basic models

We fit the spectra using a *gaussian smoothing* with trend given by our simulated unresolved lines in the broad continuum band:

- basic continuum: Continuum model (absorbed powerlaw with gaussian smoothing) after ignoring the channels in 5.-7.2 keV
- fix-fix: narrow line from neutral iron.
- fix-free: broad line from neutral iron.
- free-fix: narrow line with variable energy.
- free-free: broad iron line with variable energy

# Analysis of the Iron line using Xspec, basic models

We find:

- fix-fix: **significant at $> 4\sigma$**
- fix-free: **the line is broad at $\sim 3 - 4\sigma$** with exception of high-z
- free-fix: centroid E higher than 6.4 keV not required ($<2\sigma$)
- free-free: adjustment significant at $\sim 3 - 4\sigma$ with exception of high-z

# Analysis of the Iron line using Xspec, disk models

We add to the basic continnum, instead of a gaussian, proper models to fit the line (diskline in Xspec):

- disk-fix: Fit with `diskline` with accretion disks seen with inclination angles $i = 45^o$, with the bulk of the emission from the innermost radii (the emissivity is -2).
- disk-free: Fit with free inner radius, inclination angle and emissivity
- disk-fix-na: narrow line emission with free energy added to the disk-line emission
- disk-free-na: narrow line emission with free energy added to the disk-line emission with free parameters of the disk

# Analysis of the Iron line using Xspec, disk models

We find:

- disk-fix: **Fits the line as well as the gaussian**
- disk-free: Adjustment not required ($<2\sigma$) (with exception of high-L and high-z)
- disk-fix-na: Narrow line added to the fixed diskline not required ($< 2\sigma$) (with exception of high-z only where the sole narrow line is found at $> 3\sigma$)
- disk-free-na: Narrow line added to free diskline not required ($< 2\sigma$) with exception of the full sample only (significant at $> 3\sigma$)

# The full sample with fix-fix

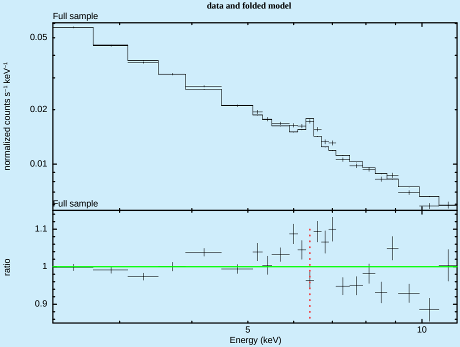



Figure: Full sample with its ratio with fix-fix

# The full sample with free-free

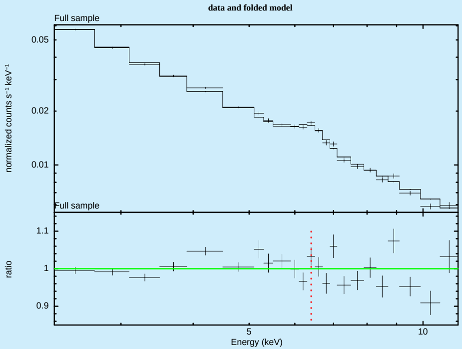



Figure: Full sample with its ratio with free-free

# The full sample with disk-fix ($\chi^2/dof = 62.94/19$)

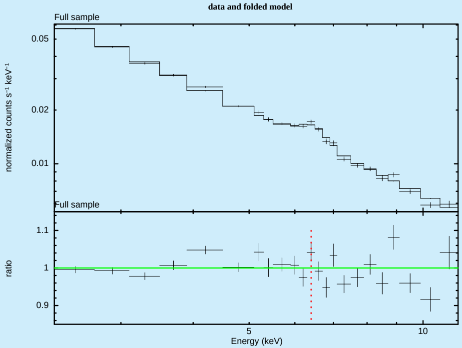



Figure: Full sample with its ratio with disk-fix: $\chi^2/dof = 62.94/19$

# Conclusions

- Using the model-indepenent analysis: **the iron line is significant at $> 4\sigma$**, with EW$=$ 129 eV in the full sample (ranging from 97 eV and 157 eV in the subsamples)
- Fitting the spectra: the line is highly required by the data
  - **The line is broad** and we fitted it with a diskline model
  - A neutral narrow line added to the relativistic line is not required: just in the full sample its significance is $>3\sigma$

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# Absorbed and unabsorbed sample

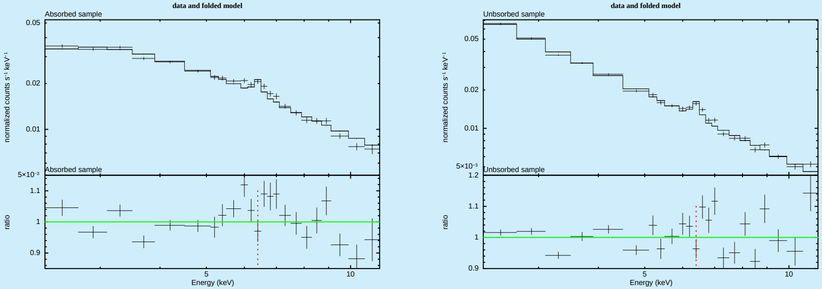



Figure: Absorbed and unabsorbed sample. Fits with fix-fix

# Absorbed and unabsorbed sample

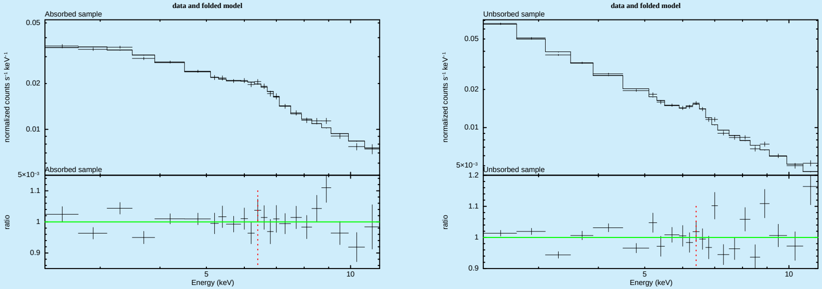



Figure: Absorbed and unabsorbed sample. Fits with free-free

# Absorbed and unabsorbed sample

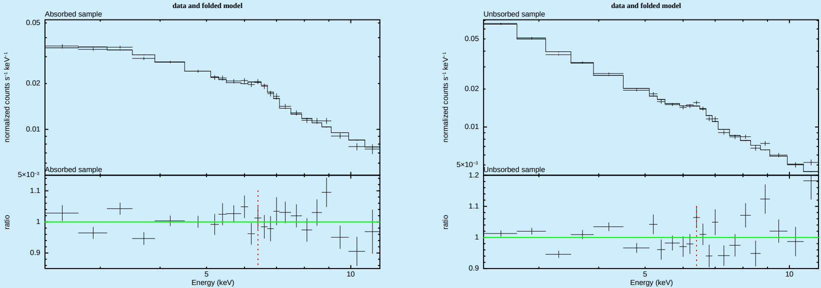
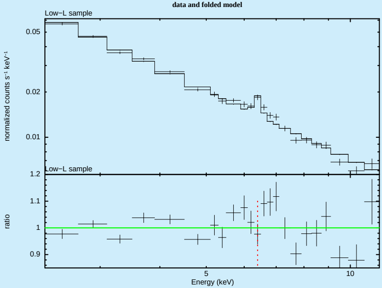
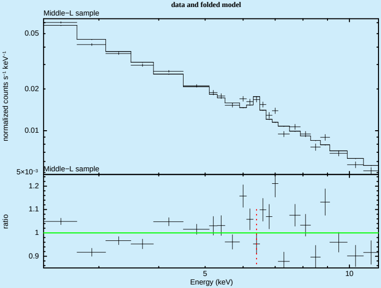


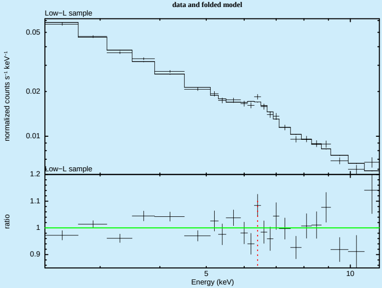

Figure: Absorbed and unabsorbed sample. Fits with disk-fix

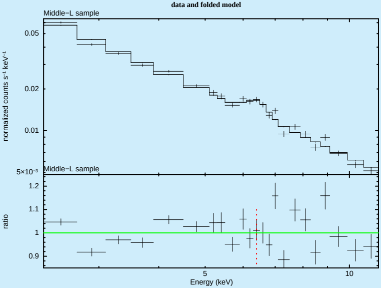
# Low-L and middle-L bins fitted with fix-fix



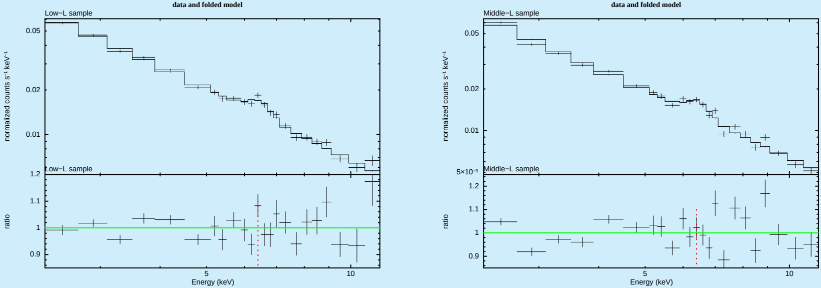



# Low-L and middle-L bins fitted with free-free



# Low-L and middle-L bins fitted with disk-fix



# Low-z and middle-z bins fitted with fix-fix

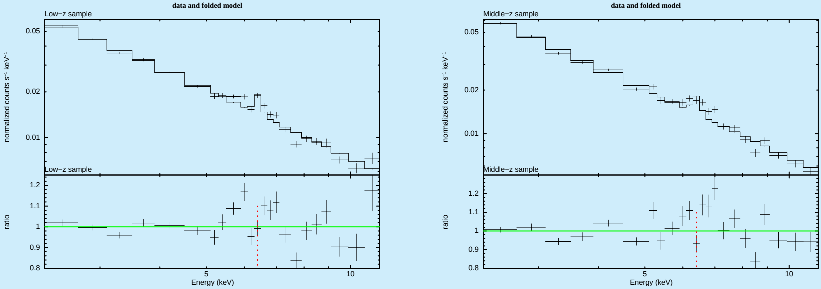
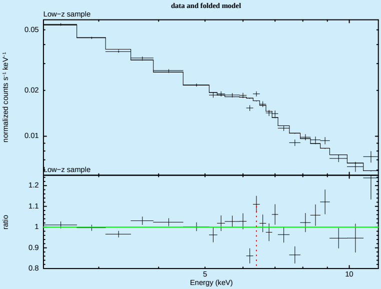



Figure: Redshift bins with fix-fix

# Low-z and middle-z bins fitted with free-free



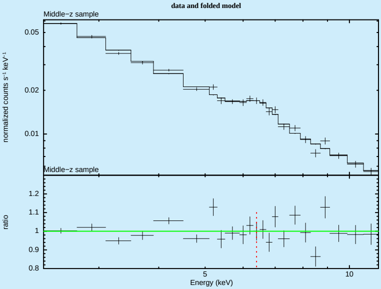




Figure: Redshift bins with free-free

# Low-z and middle-z bins fitted with disk-fix

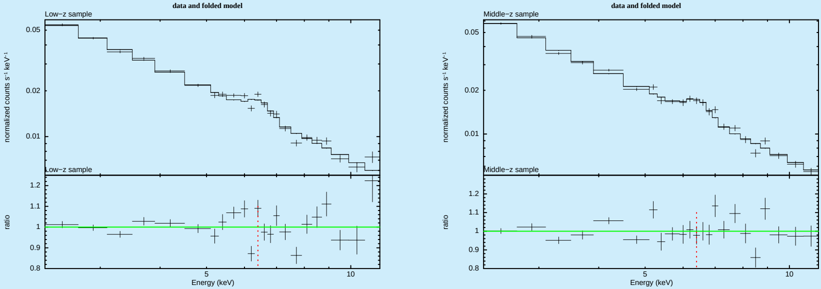
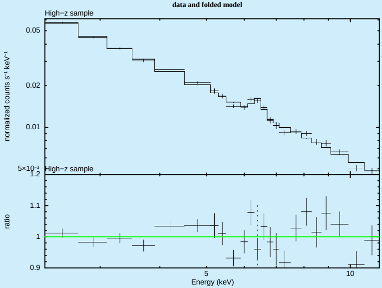
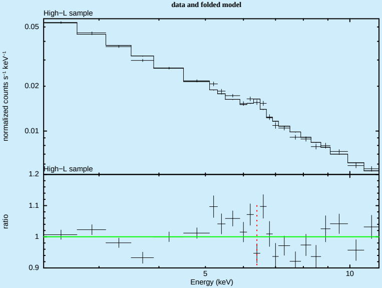


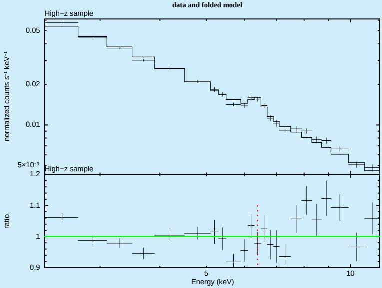

Figure: Redshift bins with disk-fix

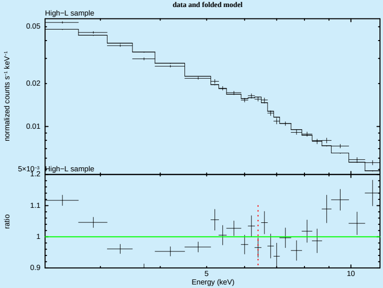
# High-L and high-z bins fitted with fix-fix



# High-z and high-L bins fitted with free-free



# High-z and high-L bins fitted with disk-fix