A *Chandra* Survey of fluorescence Fe lines in X-ray binaries at high resolution

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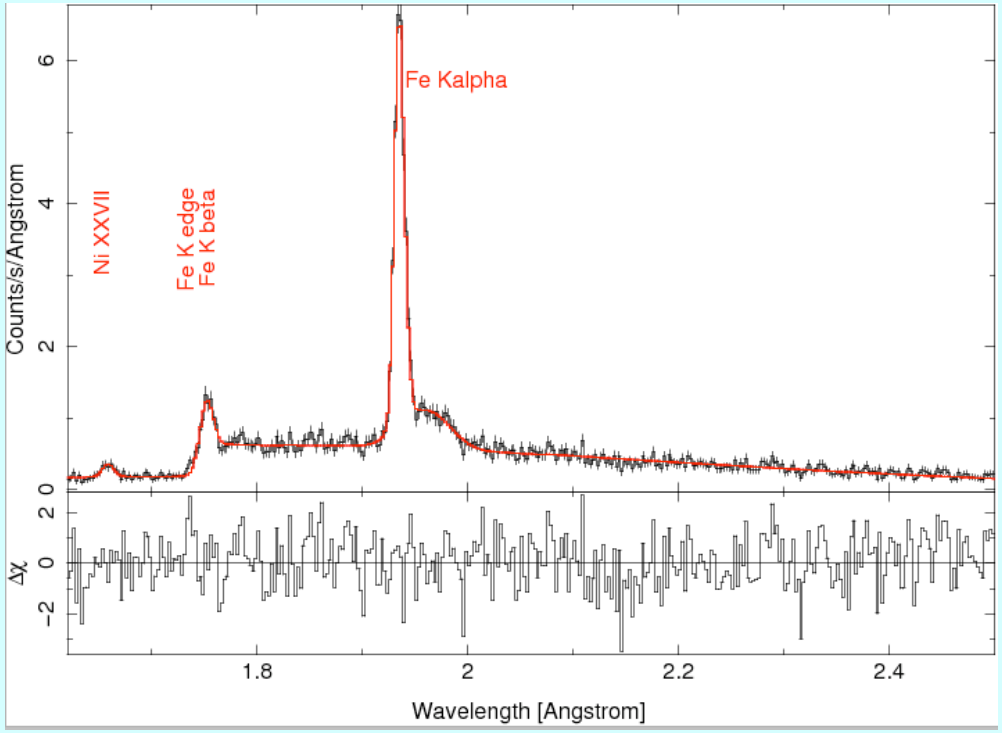
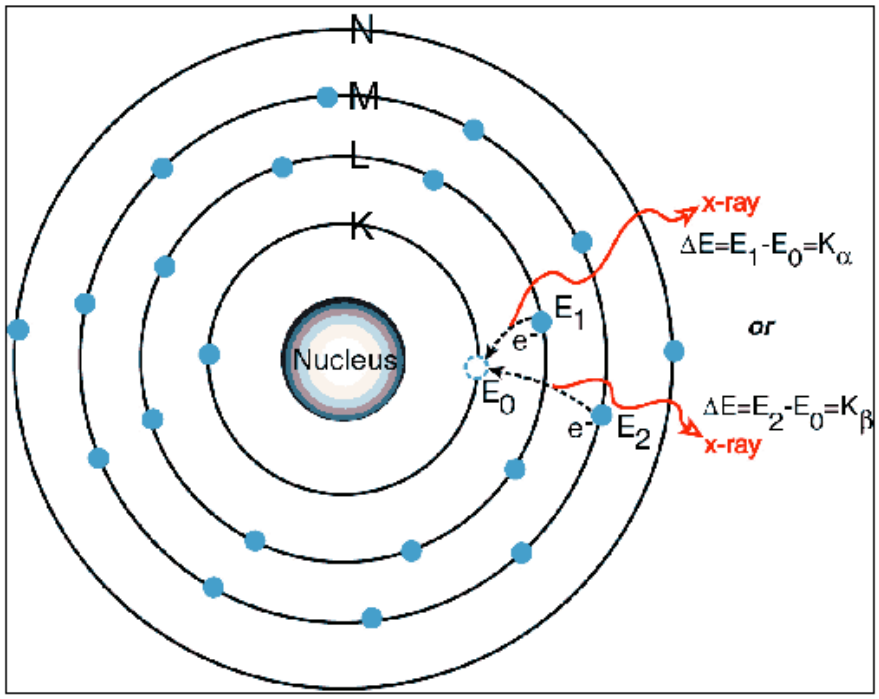




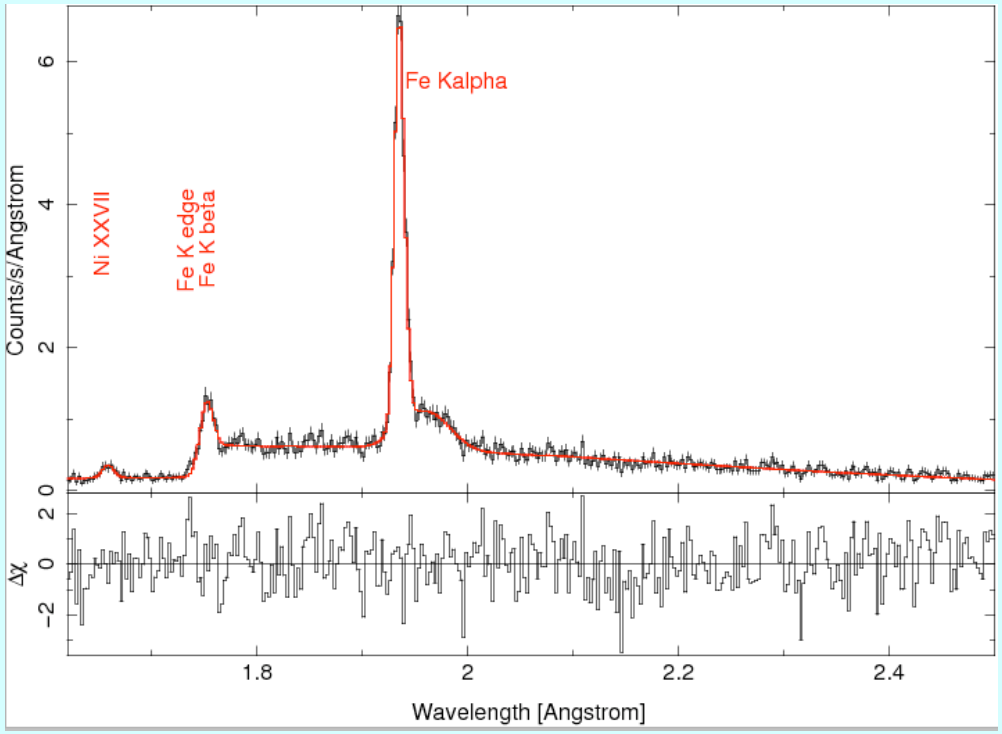
- Continuum photons with E > 7.12 keV (λ < 1.74 Å K edge) remove K shell electrons which are replenished by bound electrons from upper levels:
- L→K Kα at 1.94 Å (= 6.39 keV)
- M→K Kβ at 1.75 Å (=7.08 keV)
- Fe abundant
- Present in an unconfused part of the spectrum
- Fundamental tool to study the circumsource material.

Previous surveys

- Gottwald et al. 1995 using EXOSAT GSPC.
  - 32 XRBs:
  - 20 LMXBs (~63%): E = 6.628±0.012 keV, FWHM ≈ 1keV
  - 12 HMXBs (~37%): E = 6.533±0.003 keV, FWHM ≈ 0.5keV

- Asai et al. 2000 using ASCA GIS and SIS.
  - 20 LMXBs
  - Fe line detection in ~ 50% of the sources
  - E = 6.6 keV; large scatter 6.55 - 6.7 keV. FWHM~0.5 keV when resolved

- Present survey: 41 XRBs (= 10 HMXBs + 31 LMXBs), at the highest resolution possible today (*Chandra HETG*).

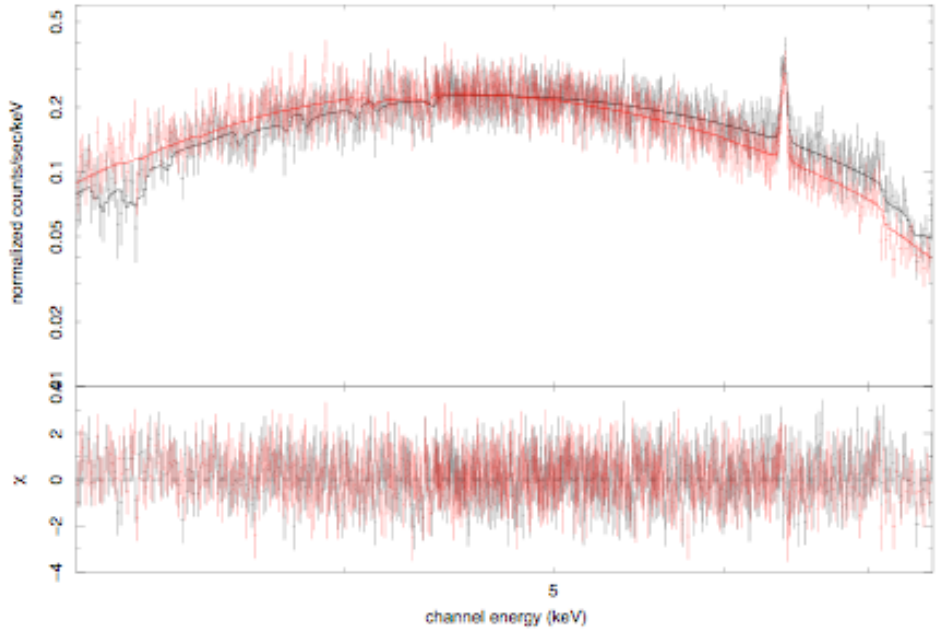


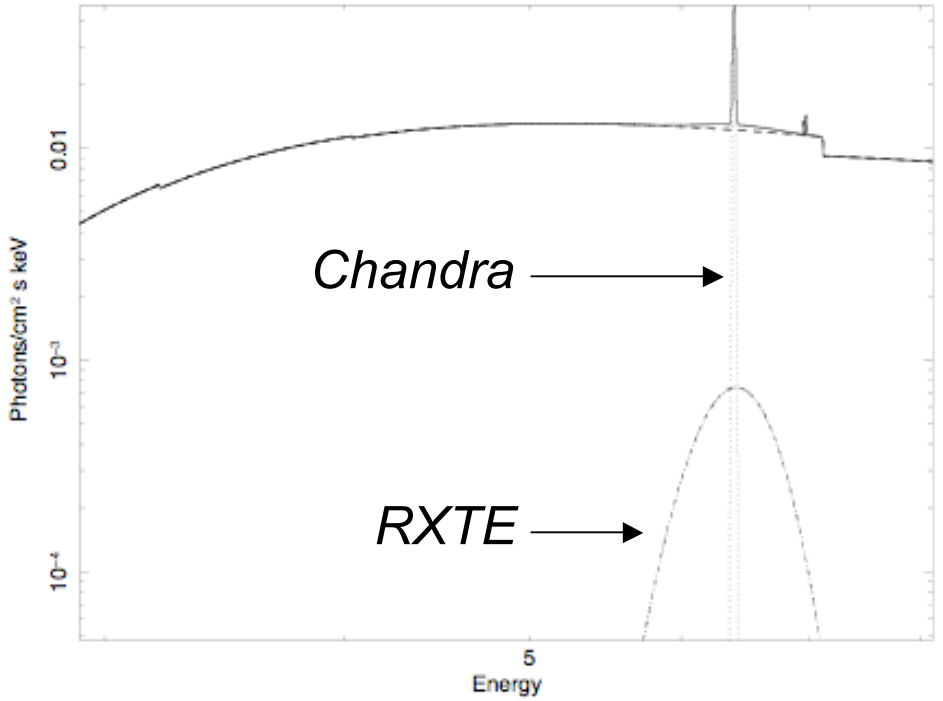
- Local continua 1.6 - 2.5 Å (≈ 4.96 - 7.74 keV)
- Simple powerlaw modified by an edge at 1.740 Å
  - K shell fluorescence of neutral Fe independent of the continuum above 1.740 Å
  - Recovery of the continuum below 1.74 Å goes as the power of 3, very fast.
  - Avoid detailed modelling of the entire continuum for every source: uncertain and controversial.

• We obtain the optical depth of the edge τ_K. Infer the equivalent density column of the reprocessing material N_H via the abundance of Fe with respect to H (assumed solar).

• Gaussians to model all emission lines present.

And broad lines?



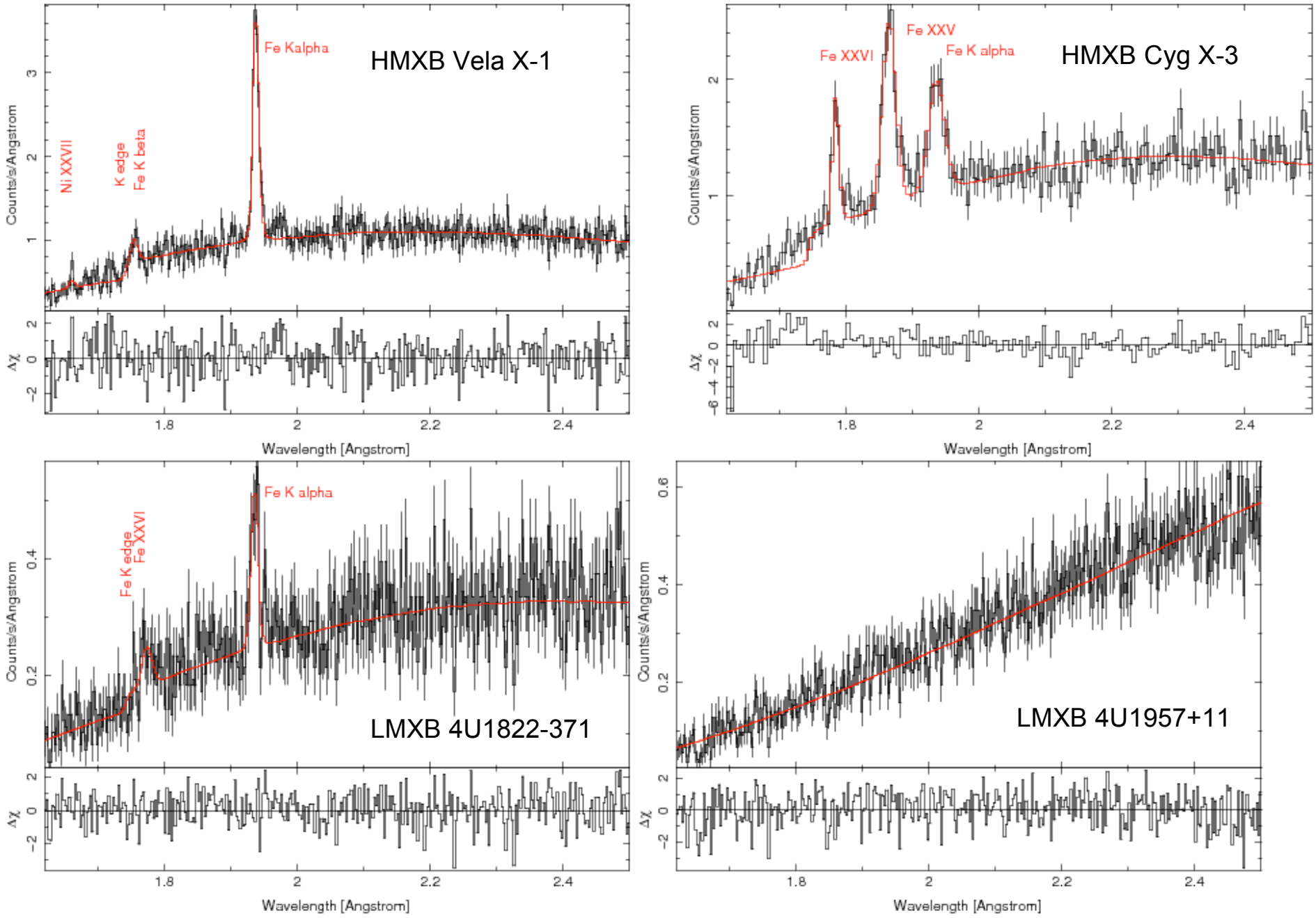


Miller et al. 2002

Hanke et al. 2009

Chandra HETG is not the instrument of choice for the study of broad lines.

This survey deals specifically with the narrow component of the Fe line


HMXB Vela X-1
Fe Kalpha
Ni XXVII
K edge
Fe K beta
HMXB Cyg X-3
Fe XXVI
Fe XXV
Fe K alpha
LMXB 4U1822-371
Fe K alpha
Fe K edge
Fe XXVI
LMXB 4U1957+11
Counts/s/Angstrom
Δχ
Wavelength [Angstrom]

First results

- Fe Kα line centred at **λ=1.9387±0.0016 Å**; compatible with fluorescence from Fe I up to Fe X; no shifts to higher ionization states nor any difference between HMXBs and LMXBs

  Reprocessing material (close to) neutral.

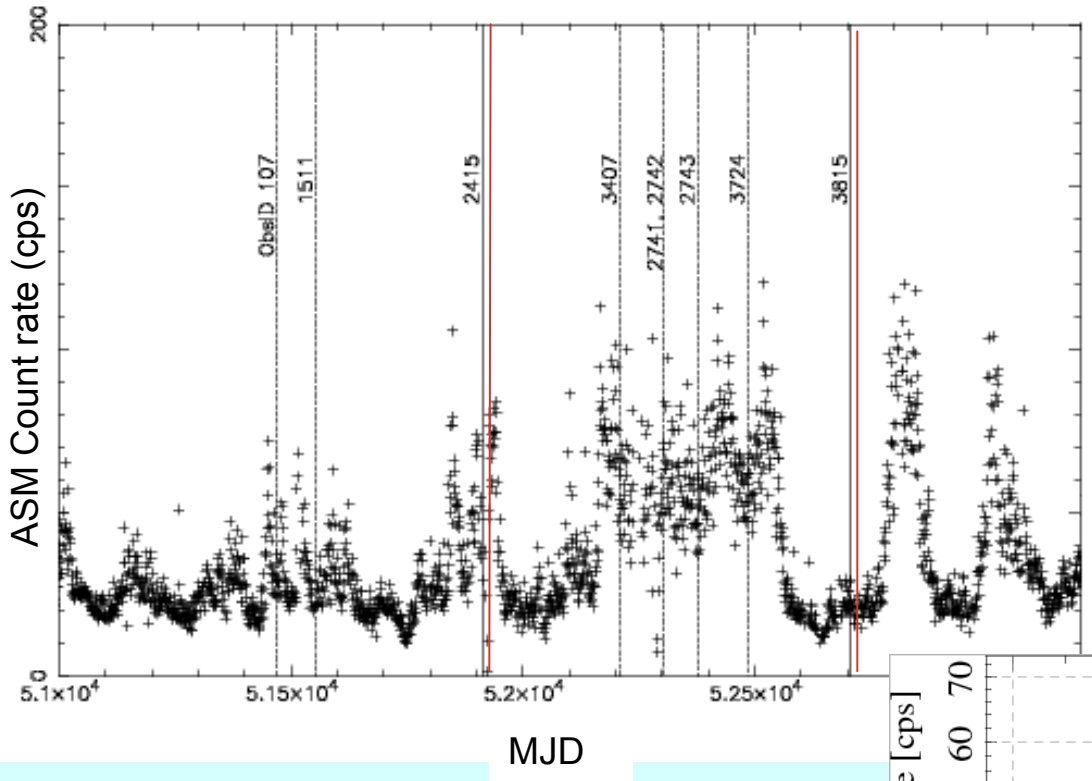
- FWHM ≤ 0.005 Å; very narrow, normally not resolved by *Chandra*

  Reprocessing material not rotating at high speeds.

First results

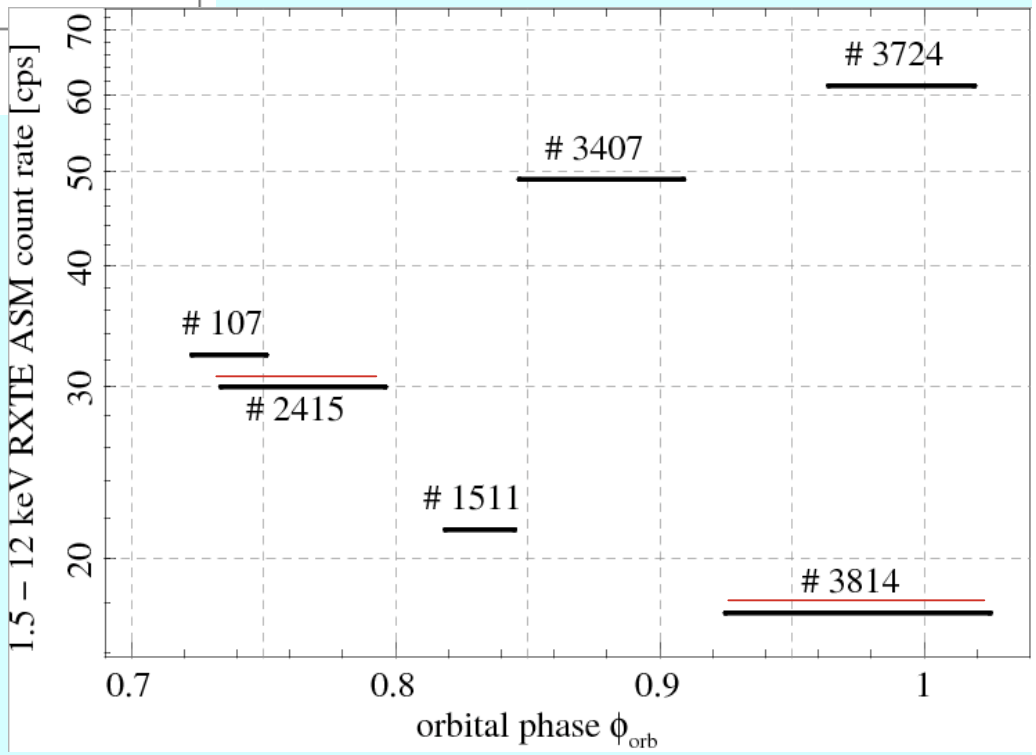
- Fe K shell fluorescence ubiquitous in all HMXBs (~100% 10 of 10). However seems to be very rare amongst LMXBs (~10% 4 of 31).
- The lack of Fe line emission is always accompanied by the lack of any detectable K edge.
- Those few (4) LMXBs show similar properties as their massive cousins.
- Emission in HMXBs seems highly variable. The most striking case is Cyg X-1: only two out of ten observations show Fe line emission.

Cyg X-1

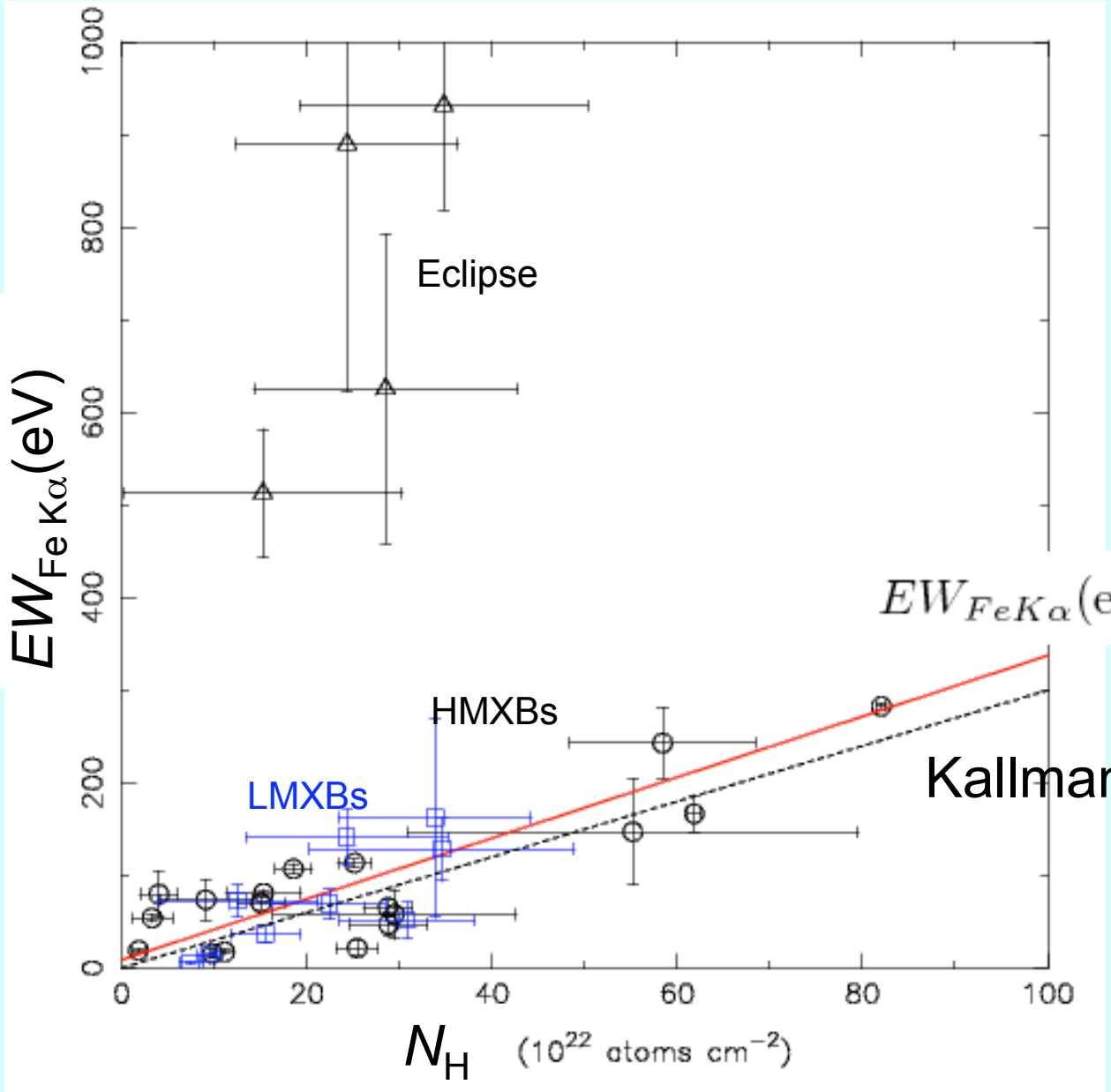


Hanke et al. 2009, ApJ 690, 330

No apparent correlation of Fe K emission with X-ray brightness (hardness) or orbital phase



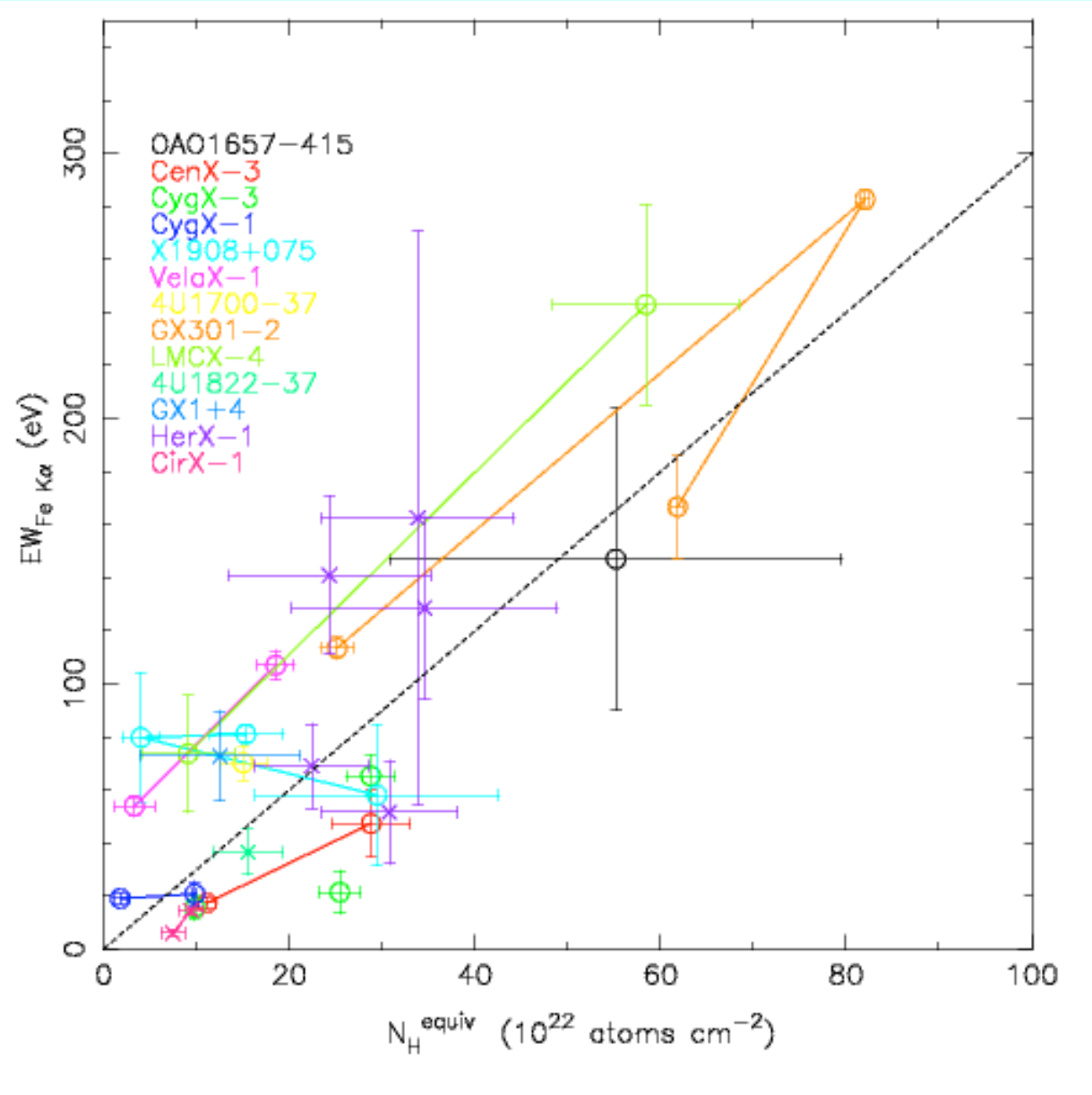
Curve of Growth



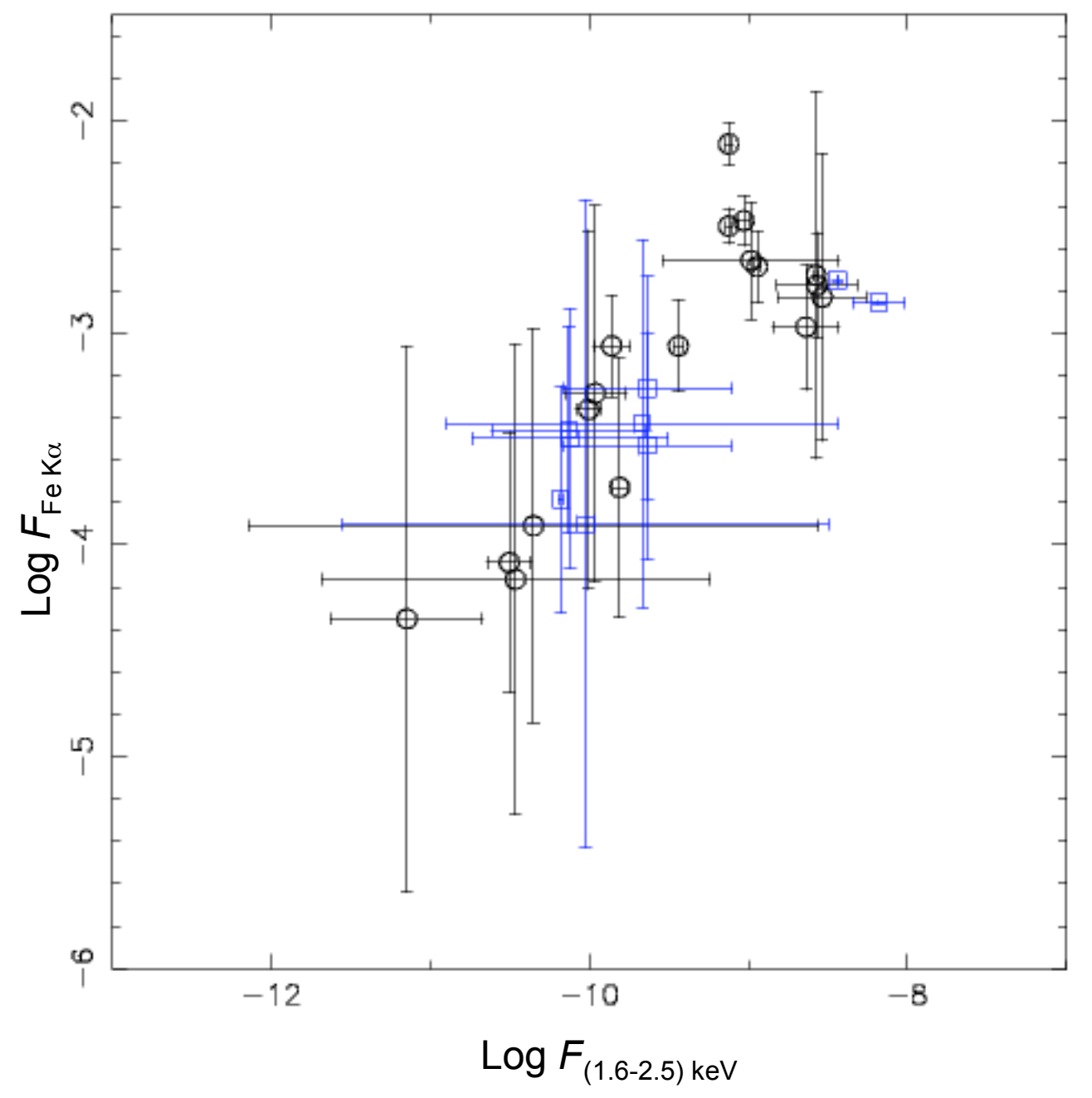
$$EW_{FeK\alpha}(\mathrm{eV}) = (3.29 \pm 0.05) N_{\mathrm{H}}^{22}$$

Kallman et al. (2004)

Curve of Growth

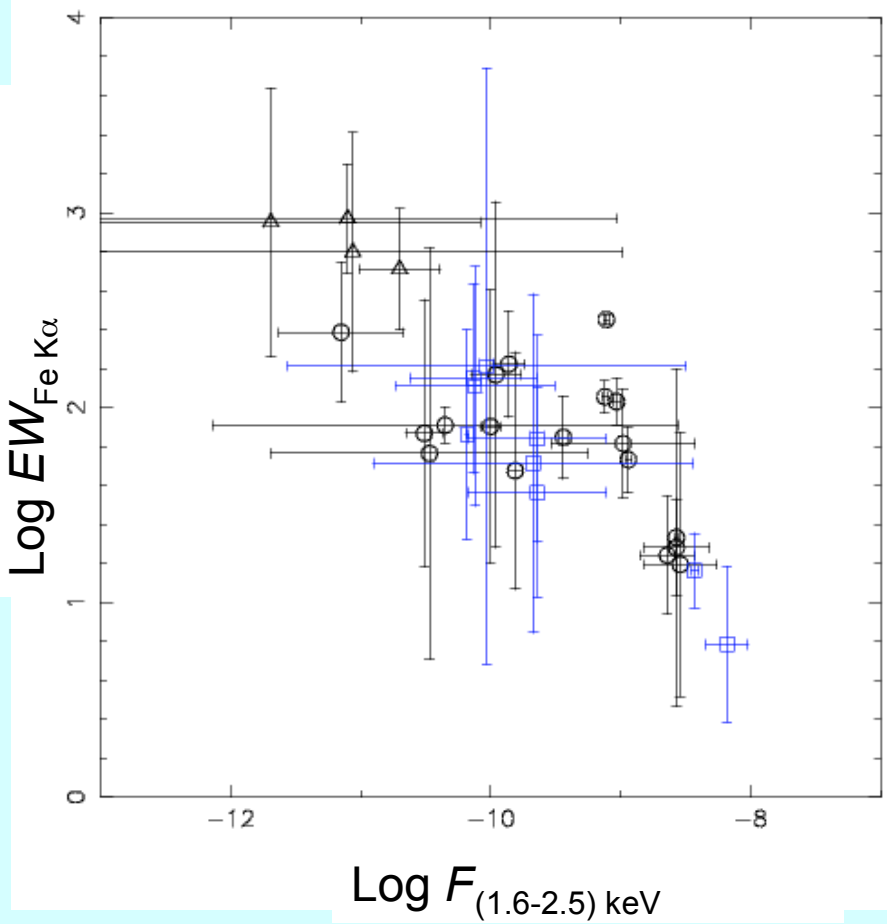


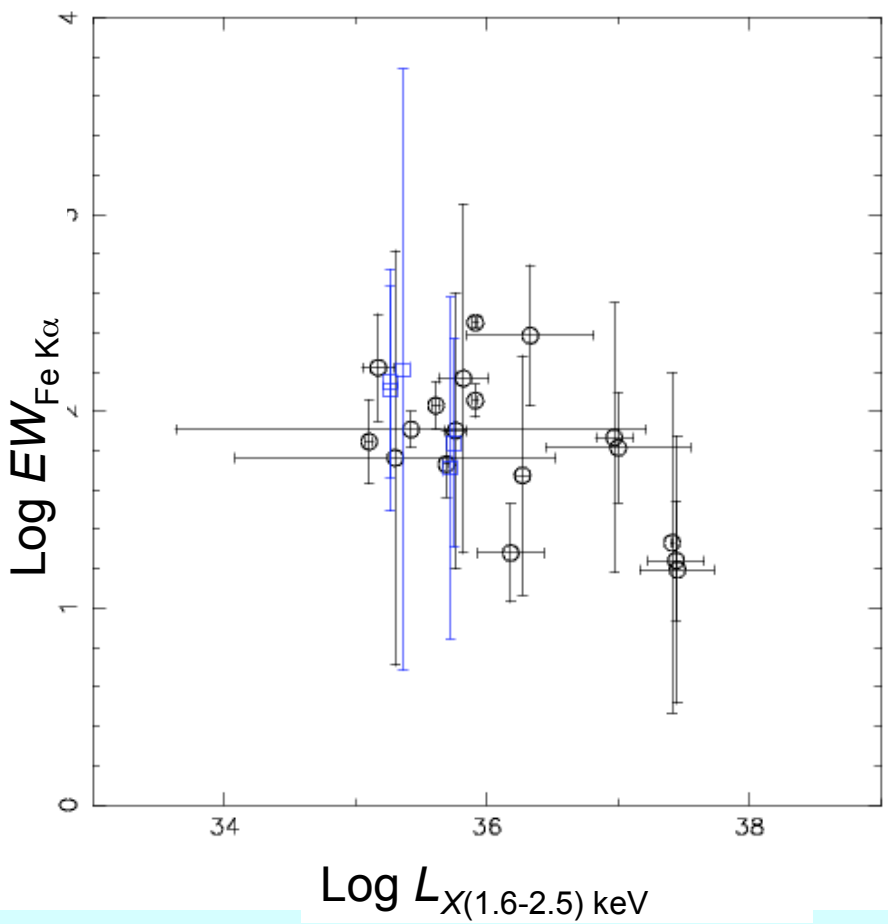
The reprocessing material is spherically distributed around the X-ray source



The reprocessing material is relatively close to the X-ray source

X-ray “Baldwin Effect”





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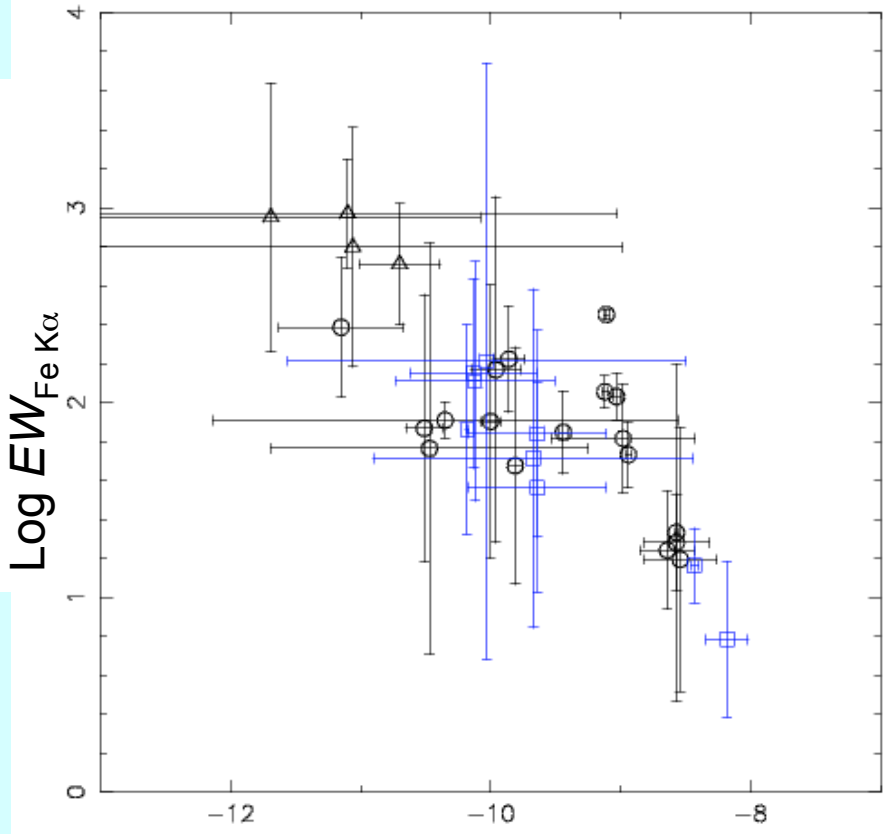

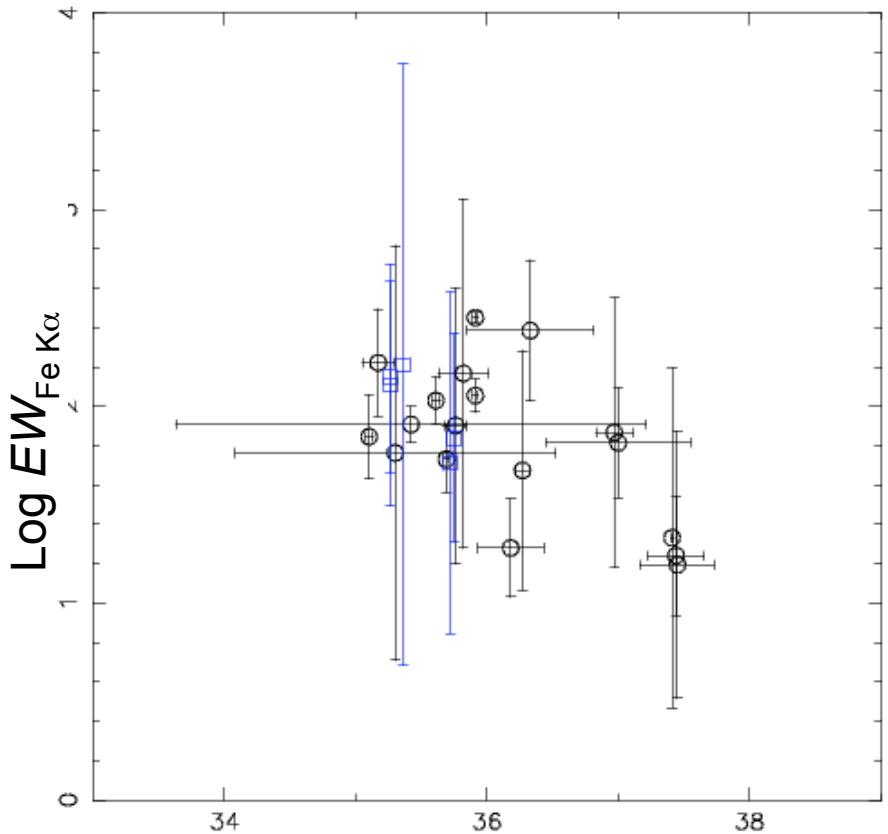

The reprocessing material becomes progressively ionized with increasing X-ray illumination, with the concurrent decrease in the Fe K shell fluorescence.

Conclusions

- We present the most comprehensive study of Fe K shell fluorescence lines to date, at the highest resolution possible.
- Fe Kα fluorescence line compatible with Fe I-X; no shifts to higher ionization states nor any difference between HMXBs and LMXBs
- FWHM $\leq$ 0.005 Å; very narrow, normally not resolved by *Chandra*
- Fe K shell fluorescence ubiquitous in all HMXBs. However seems to be very rare amongst LMXBs.
- We present the observational Curve of Growth *EW*(FeKα) vs N_H: the reprocessing material is spherically distributed around the X-ray source
- First evidence of *X-ray Baldwin effect* for XRBs as a class: Fe becomes progressively ionized with increasing L_x.
- This effect can explain the lack of Fe Kα in high (soft) states of the BH Cyg X-1. In LMXBs: the lack of Fe Kα line could mean disks too hot .