Stacking photons in deep and large Chandra surveys

Marcella Brusa
(MPE - CSST@UMBC – SAO/CfA)

A. Comastri, R. Gilli (INAF-OABo)
F. Fiore (INAF-OARoma)
F. Civano (CfA)

Outline

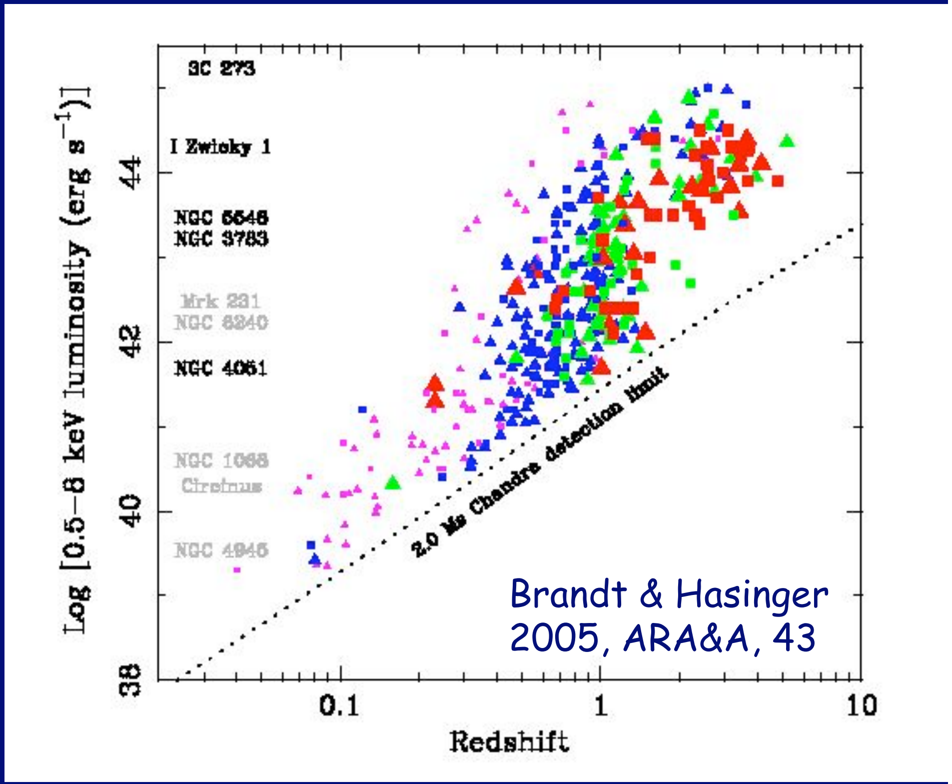
- Power of stacking
- Review on most recent results
- Focus on:
  1) Average properties of faintest X-ray sources
  2) Unveiling obscured accretion
  3) Iron line emission in cosmological context
- Summary & perspectives

AGN science close to and beyond the Chandra detection limit

- Search for obscured accretion population of most obscured, high-z sources (e.g. NGC1068, NGC6240)

Detection and/or analysis of single sources is difficult/hampered even in the deepest Chandra fields

- Low luminosity tail of AGN luminosity function
- Low counting statistics: spectral properties of the sources making the XRB
- Source populations not emitting in X-rays (e.g. ellipticals, SF)
- Resolving the unresolved XRB



How to reach them? Stacking!

- Increase the exposure by summing together X-ray emission → loose information on the single sources, but gain (a lot!) on the average population
- Push to more than 2 order of magnitudes deeper than the nominal exposures (equivalent to 100 Ms or more..)
- Stacking of both images (detection) and spectra (study spectral properties)
- Spectral properties: both Chandra and XMM
- Detection: Chandra background very low → feasible only with Chandra

Major results from Chandra stacking

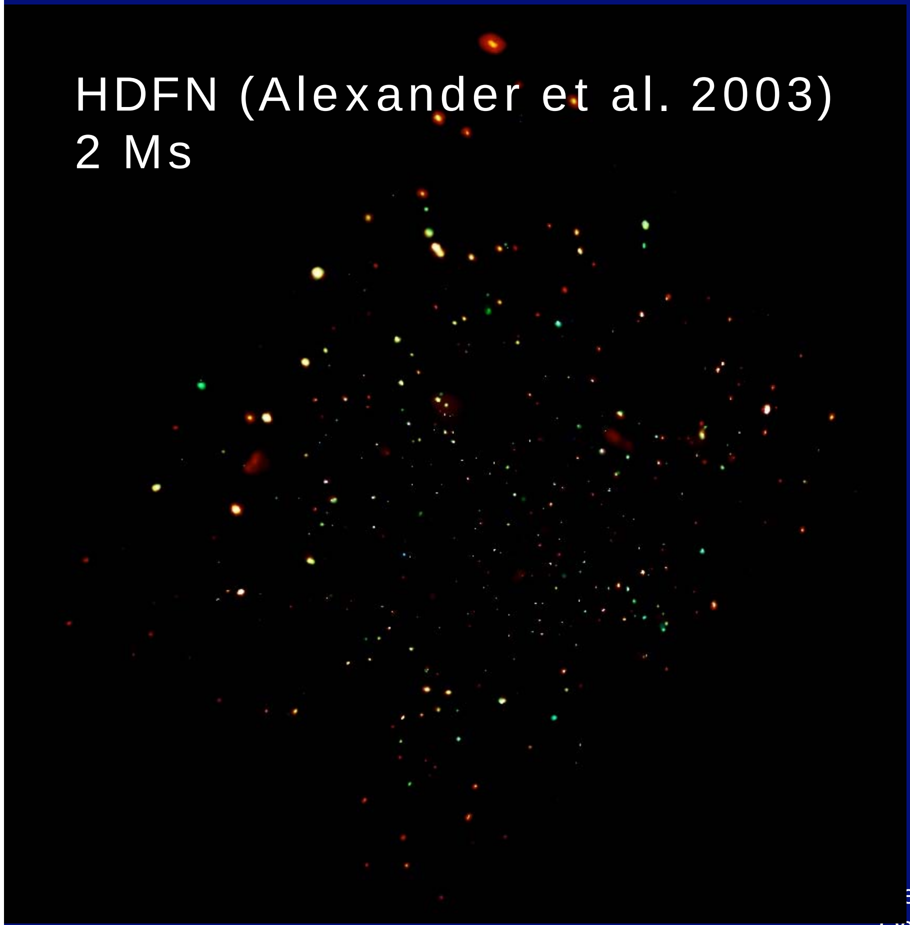
- **Resolving the XRB:**
  >400 Ms / Gs – absolute intensity, resolved fraction, constraint on undetected sources (Worsley et al. 2005,2006, Hickox & Markevitch 2006,2007, Steffen et al. 2007)

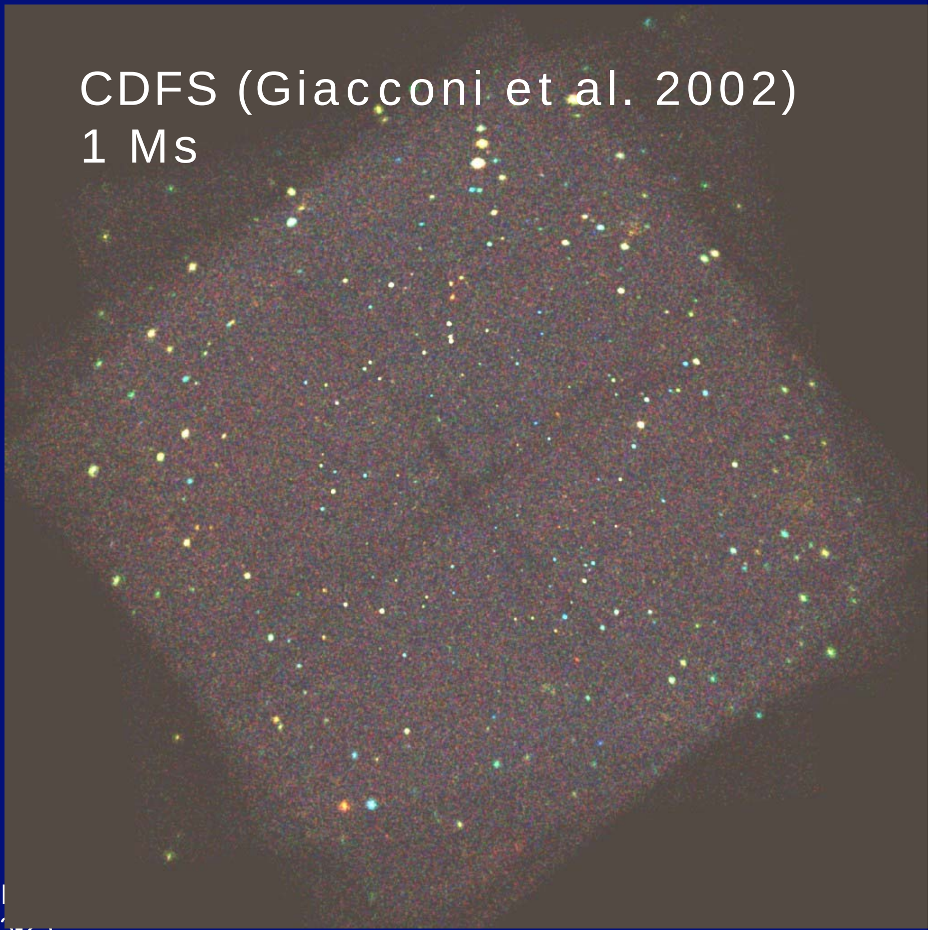
- **Imaging/detection:**
  LBG [~20-200 Ms] – Chandra revealed on-going SF up to z~3 (Nandra+02, Lehmer+05, Laird+06)
  ellipticals/spiral galaxies [~20-200 Ms] – Chandra put constraints on AGN fraction and evolution - (Hornschemeier+02, Griffiths+02, Lehmer+07, Brand+06, Rodighiero+07, Kim's poster)
  IR selected
    eros, [~10-20 Ms] – Chandra revealed X-ray dichotomy in old and dusty systems (Alexander+02, Brusa+02)
    SBzK: [~100 Ms] – Chandra revealed starforming emission (Daddi+04)
    MIPS selected: [~100 Ms] - Chandra revealed CT AGN at z~2 (Fiore+07, Daddi+07)

- **Spectroscopy:**
  - deep field sources → hardening of the spectra (e.g. Rosati+02, Alexander+03)
  - high x/o → most obscured population (e.g. Civano+05)
  - high-z quasars → dawn of X-rays universe (Vignali+03,04)
  - scuba galaxies → Compton thick obscuration (Alexander+05)
  - Iron line →footprint revealed in XRB (Brusa+05)

The deepest X-ray sky

Chandra Deep Field Surveys →
Megaseconds exposures

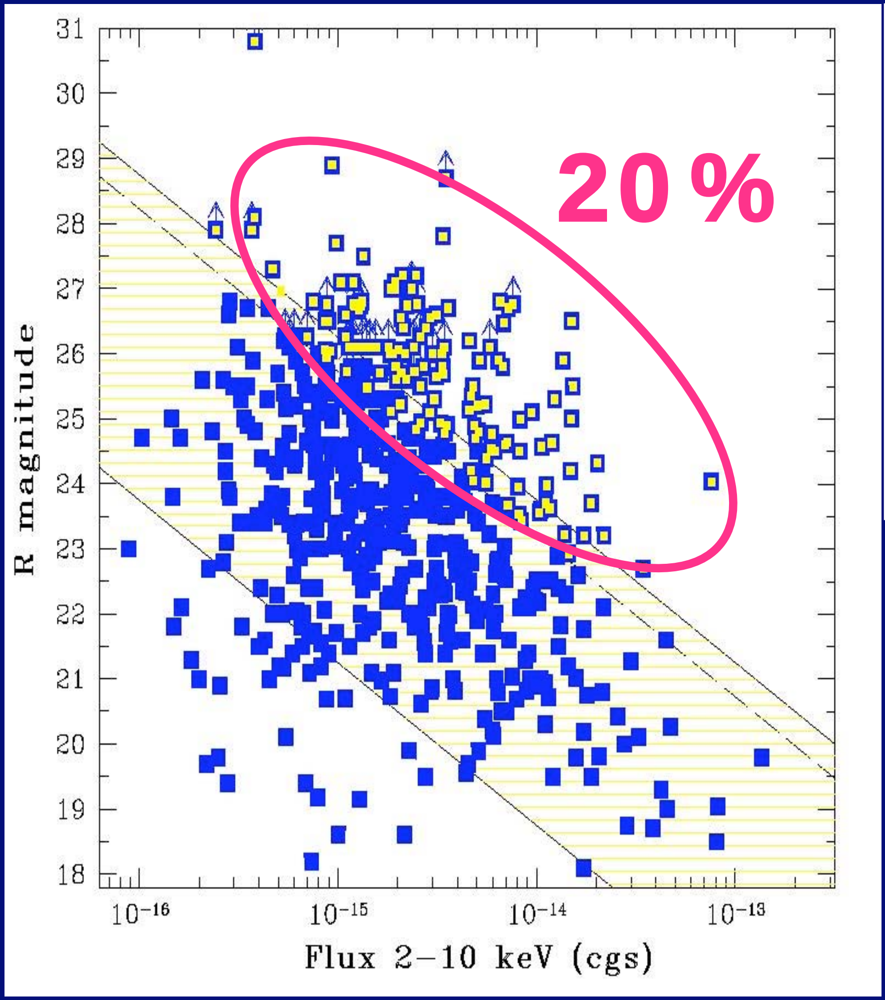




Spectral properties of the optically faint X-ray population

Civano, Comastri & Brusa, 2005, MNRAS 358, 693

- Optically faint X-ray population is X-ray “bright” (high X/O ratio, see e.g. Alexander et al. 2001)
- Expected to be the most obscured one
- Individual spectral analysis feasible/reliable only for few bright objects (see Tozzi et al. 2006)
- Investigate the average properties of this X-ray population



The sample:

137 sources:

63 CDFN +74 CDFS

Only **39 redshifts**

19 spectroscopic

18 photometric

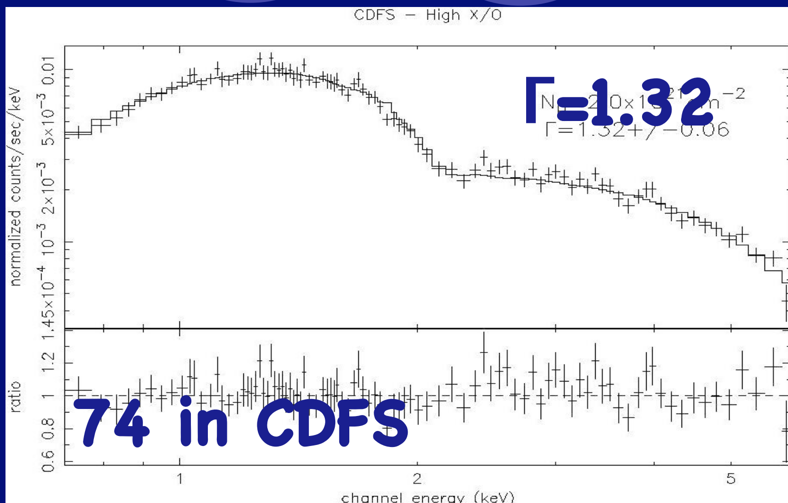
✓15%-20% of the total hard sample

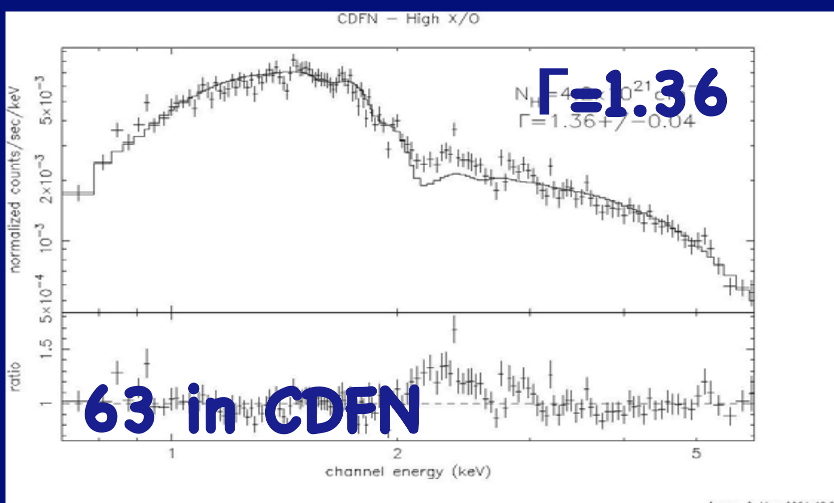
✓too faint R>24 for optical spectroscopy

✓X-ray medium-bright

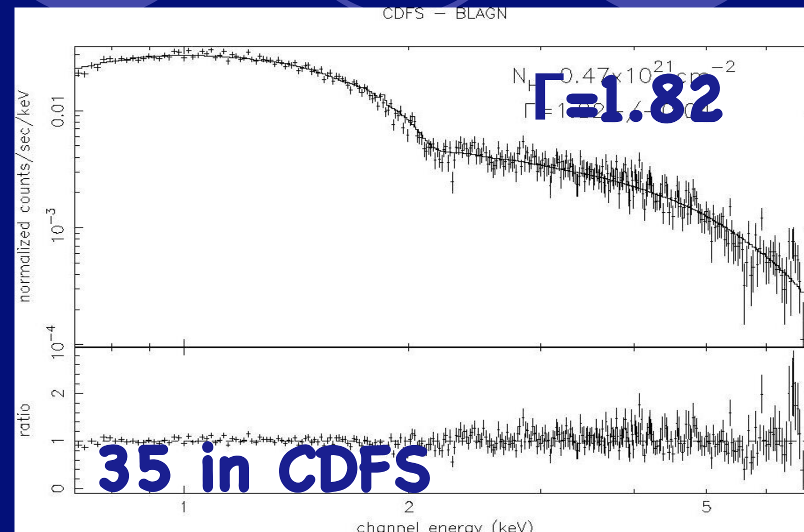
Average stacked spectra (absorbed power law)

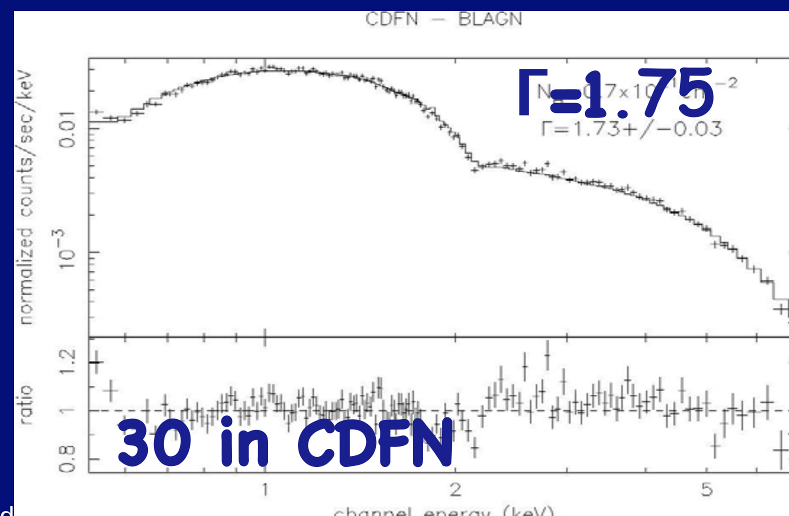
High X/O sources

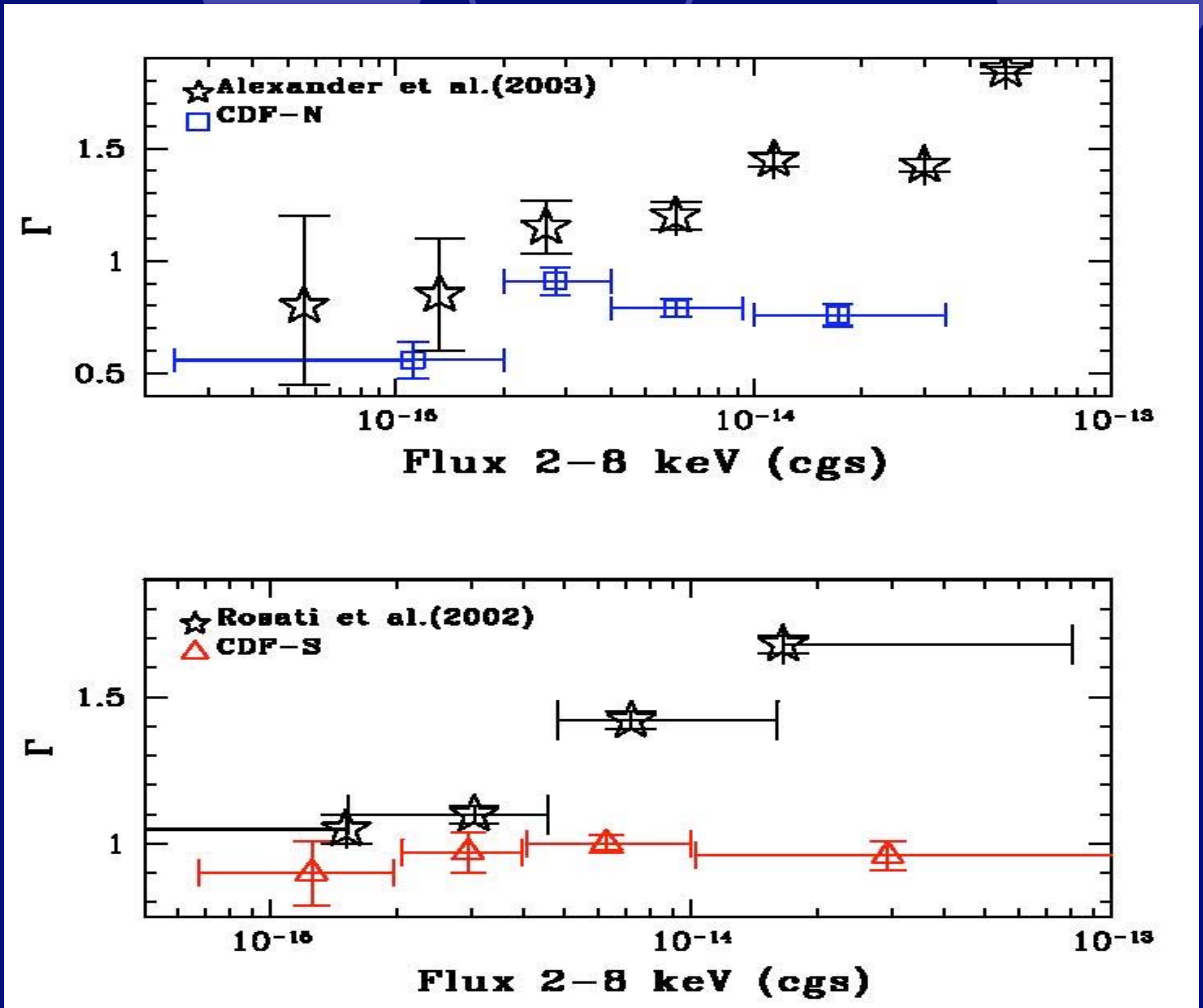




Comparison sample: BL AGN







Flux dependence:
No significant change of gamma as a function of flux →
optically faint sources represent the **most obscured component** at all fluxes

Individual fits of a few of the brightest objects (e.g. Comastri, Brusa & Civano 2004, Tozzi et al. 2006) and of stacked spectra in different redshift bins imply column densities in the range $10^{22-23.5}$ cm^{-2}.

Unveiling obscured accretion

Fiore et al. 2007, ApJ in press, astro-ph/07052864

- X-ray surveys: very efficient in selecting unobscured and moderately obscured AGN but miss most highly obscured AGN (e.g. Worsley et al. 2005)
- IR surveys: AGNs highly obscured at optical and X-ray wavelengths shine in the MIR thanks to the reprocessing of the nuclear radiation by dust (Martinez-Sansigre et al. 2005, Polletta et al. 2006)
- Goal: combining X-ray and IR surveys to get the SMBH census and compile bolometric luminosity function for AGN (with no incompleteness for Compton Thick sources)
- Select candidate luminous obscured AGN by imposing:

24 micron bright fluxes (luminous) +

optically faint red sources (optically obscured) →

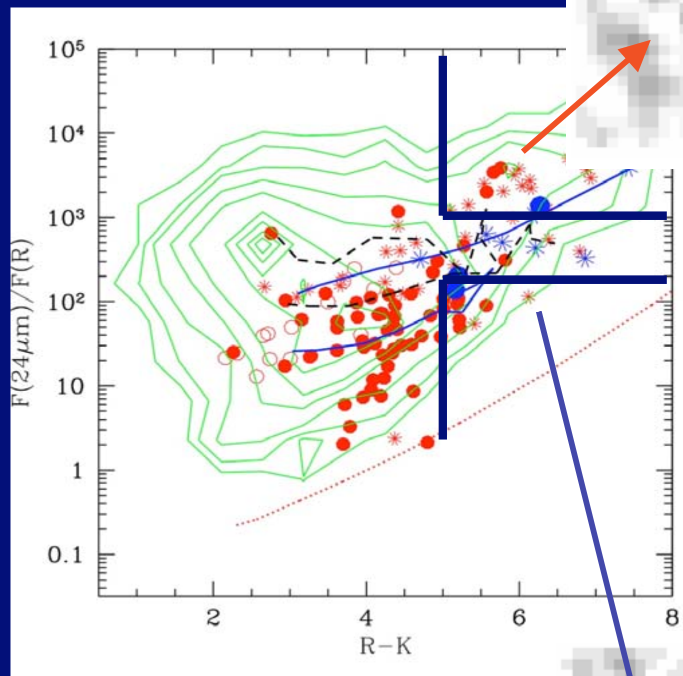
high MIR/O ratio + R-K>4.5

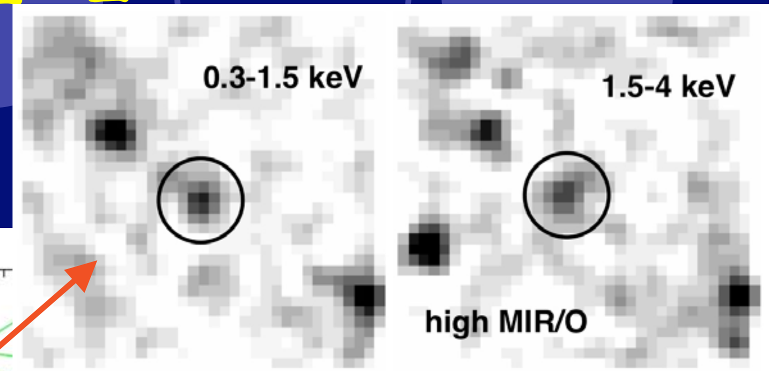
Combining MIR/O and R-K criteria: selection of CT AGN at z~2

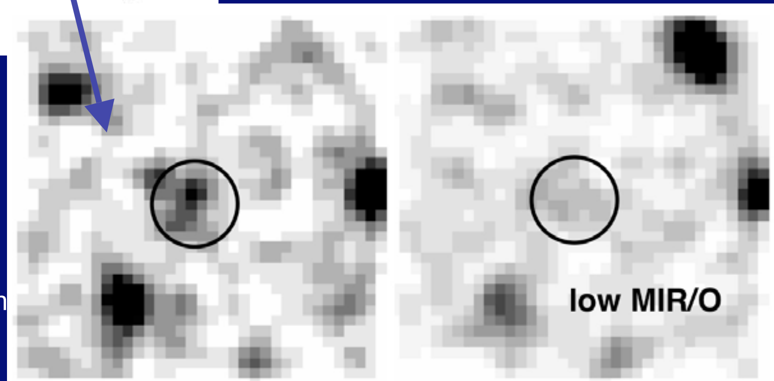
GOODS CDFS field
+
MUNICS MW catalog (Spitzer+HST+VLT)

~110 obscured AGN candidates

Stack of Chandra images excluding X-ray detections in two different MIR/O and R-K bins



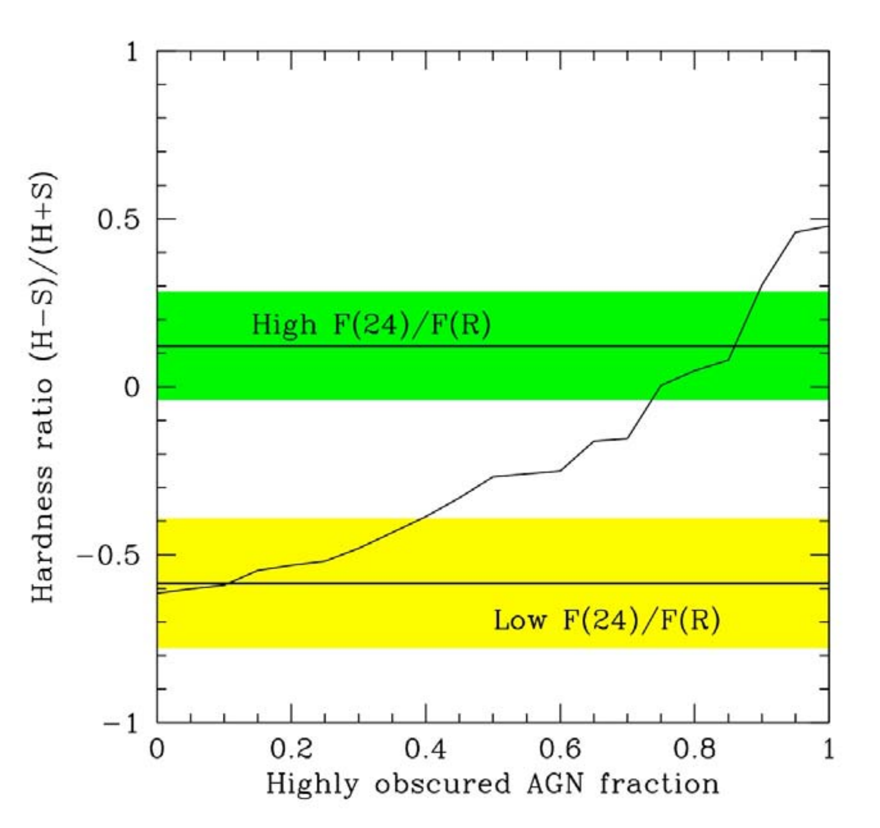


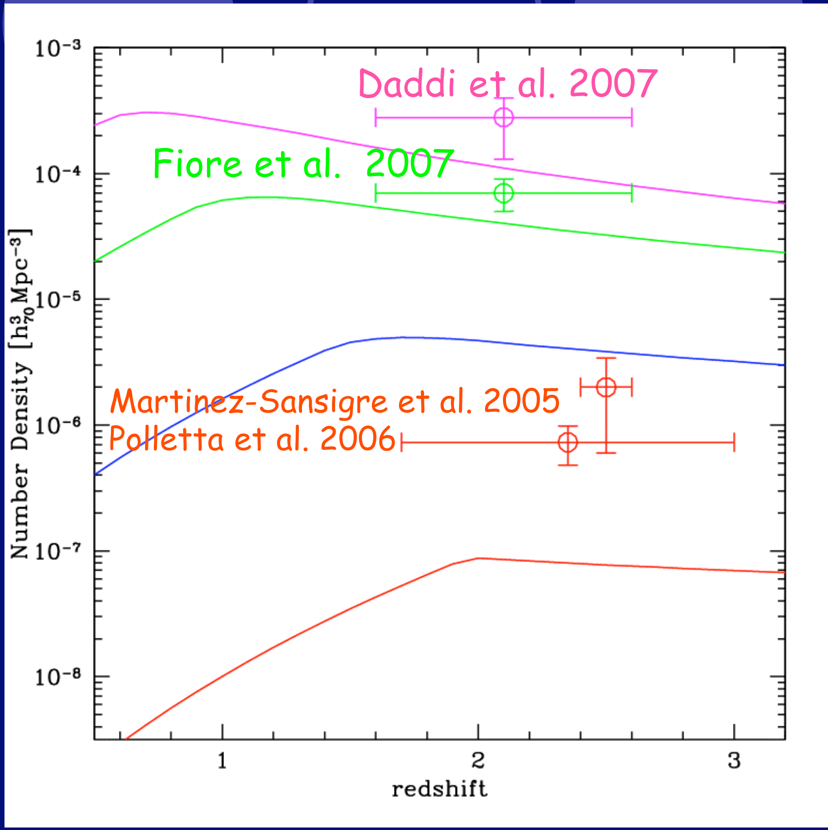


Fiore et al. 2007

See also Daddi et al. 2007

A new population of CT AGN





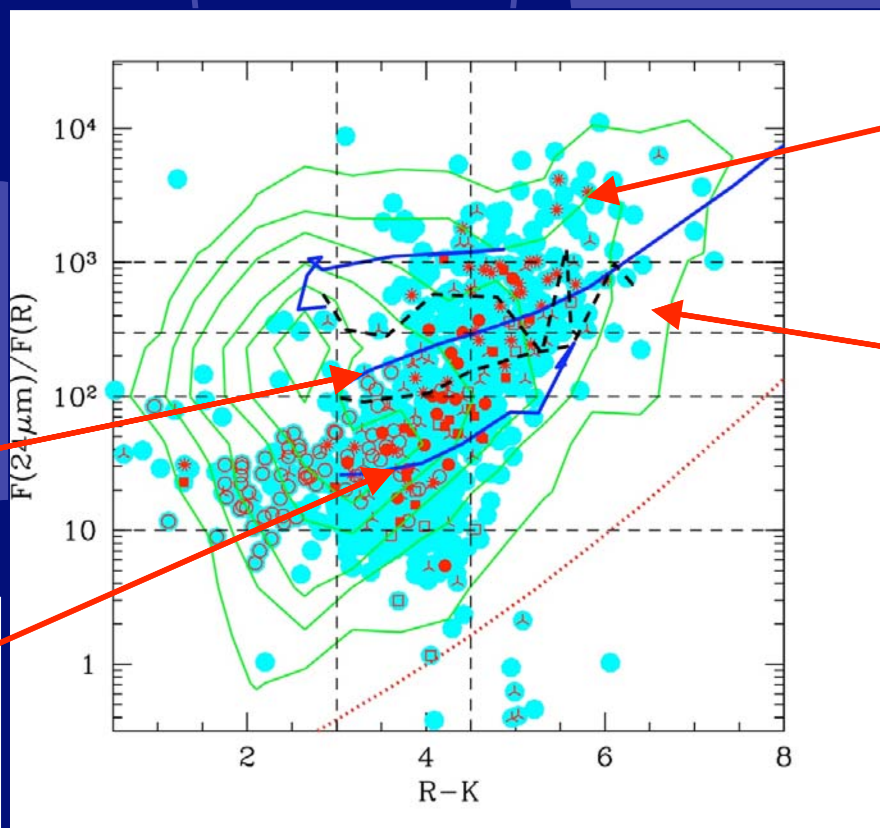
The observed MIR luminosity and the observed HR imply (unobs) Lx>43 and NH>24 for ~80% of the sources

Curves: model predictions from Gilli, Comastri & Hasinger (2007) for L> 42, 43, 44, 45

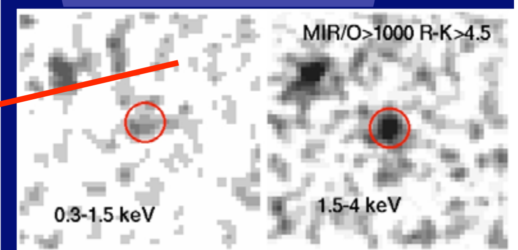
z~2 CT AGN in C-COSMOS

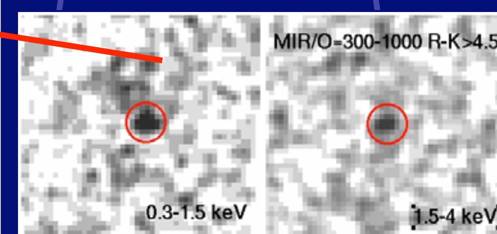
(see Puccetti's talk)

Contours = GOODS CDFS 24micron sources
Cyan = COSMOS 24 micron sources
Red = C-COSMOS detections

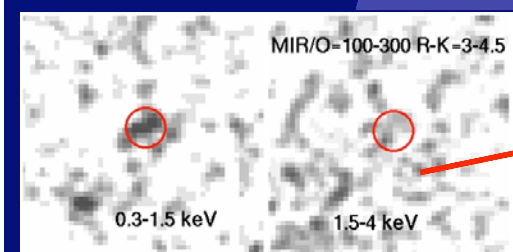


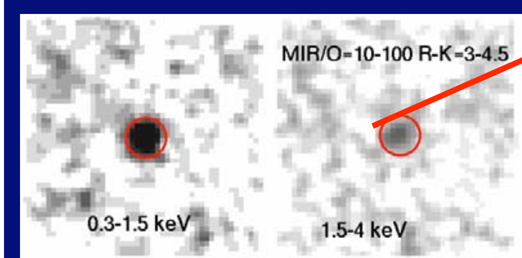
R-K > 4.5
Decreasing MIR/O





R-K = 3-4.5
Decreasing MIR/O





The Iron line background

Brusa, Gilli & Comastri, 2005, ApJL, 621, 5

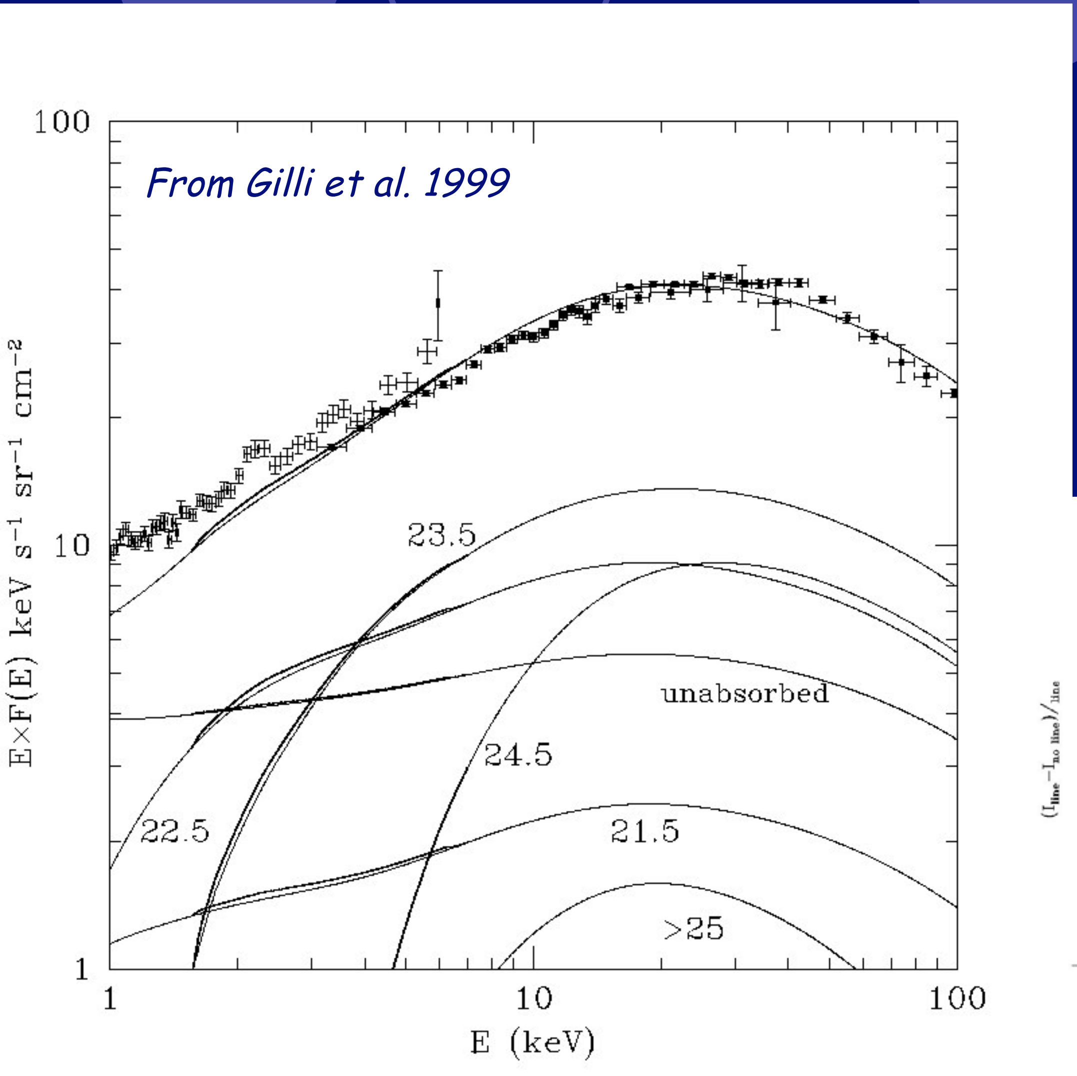
- AGN emit Iron line + XRB is made by AGN
  → "Iron feature" should be seen in the XRB spectrum (Matt & Fabian 1994)

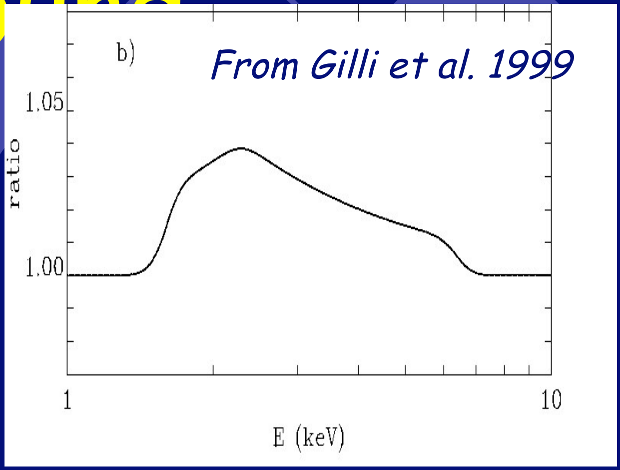
- Iron feature is smeared out by redshift
  → Max contribution: 3-7% at ~2-3 keV (Gilli et al. 1999, Gandhi & Fabian 2002)

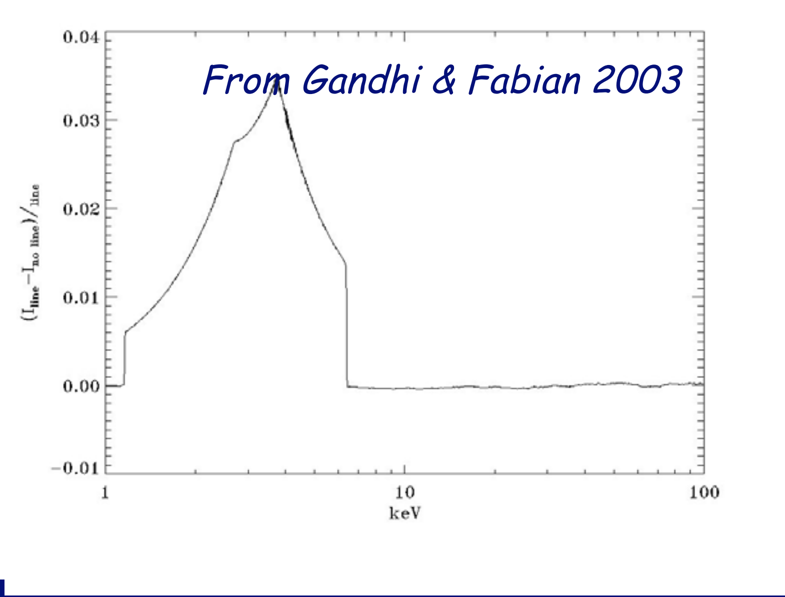
- Besides the uncertainties on the absolute normalization (up to 30%) the accuracy of present observations is not such to detect the iron feature at the level expected by model predictions

- Search for iron feature over restricted redshifts intervals (i.e. energy ranges)
  → The feature is not smeared by the cosmological evolution
  → The expected intensity is of the order of 50% above the continuum

The Iron line background







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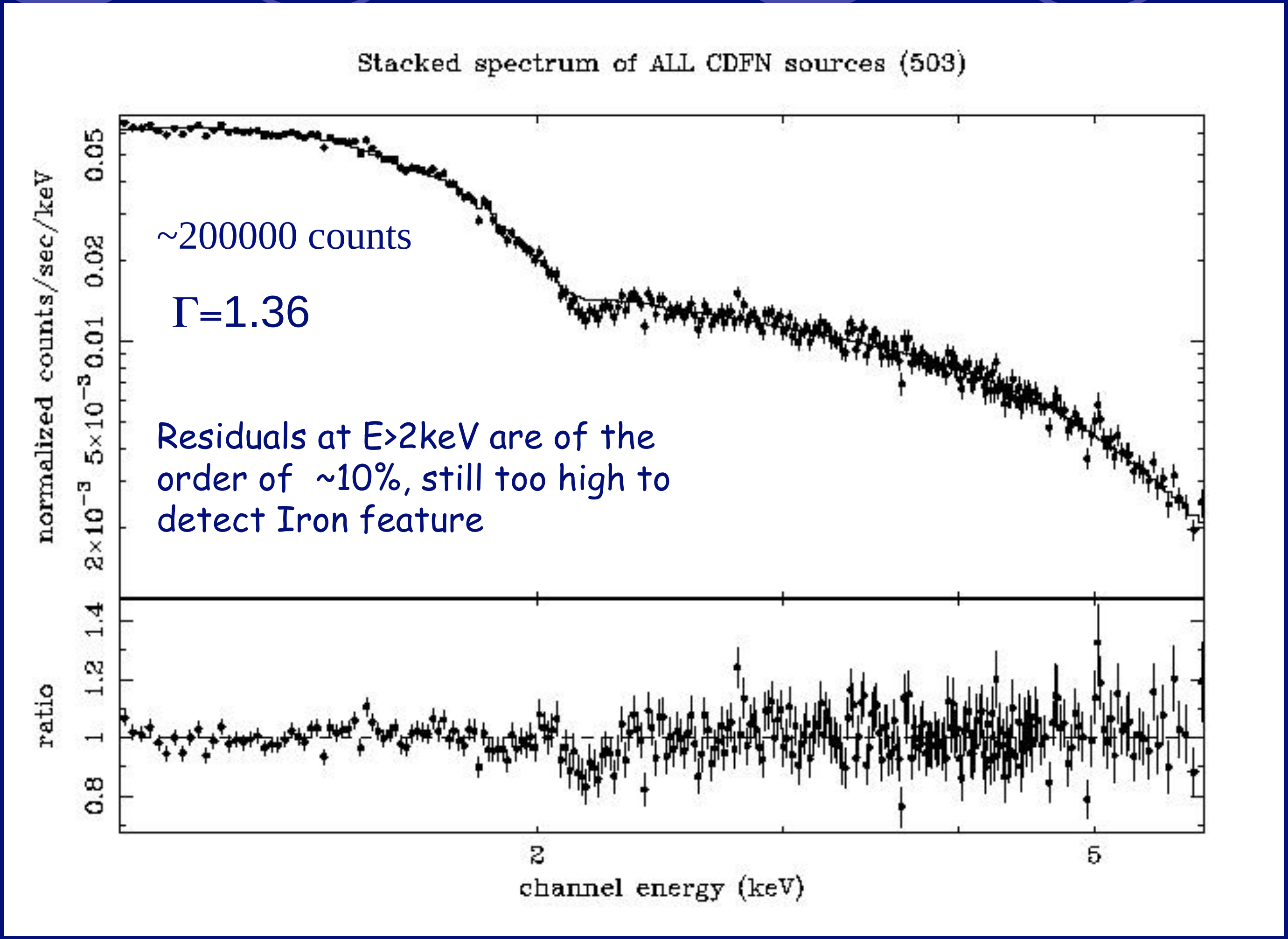
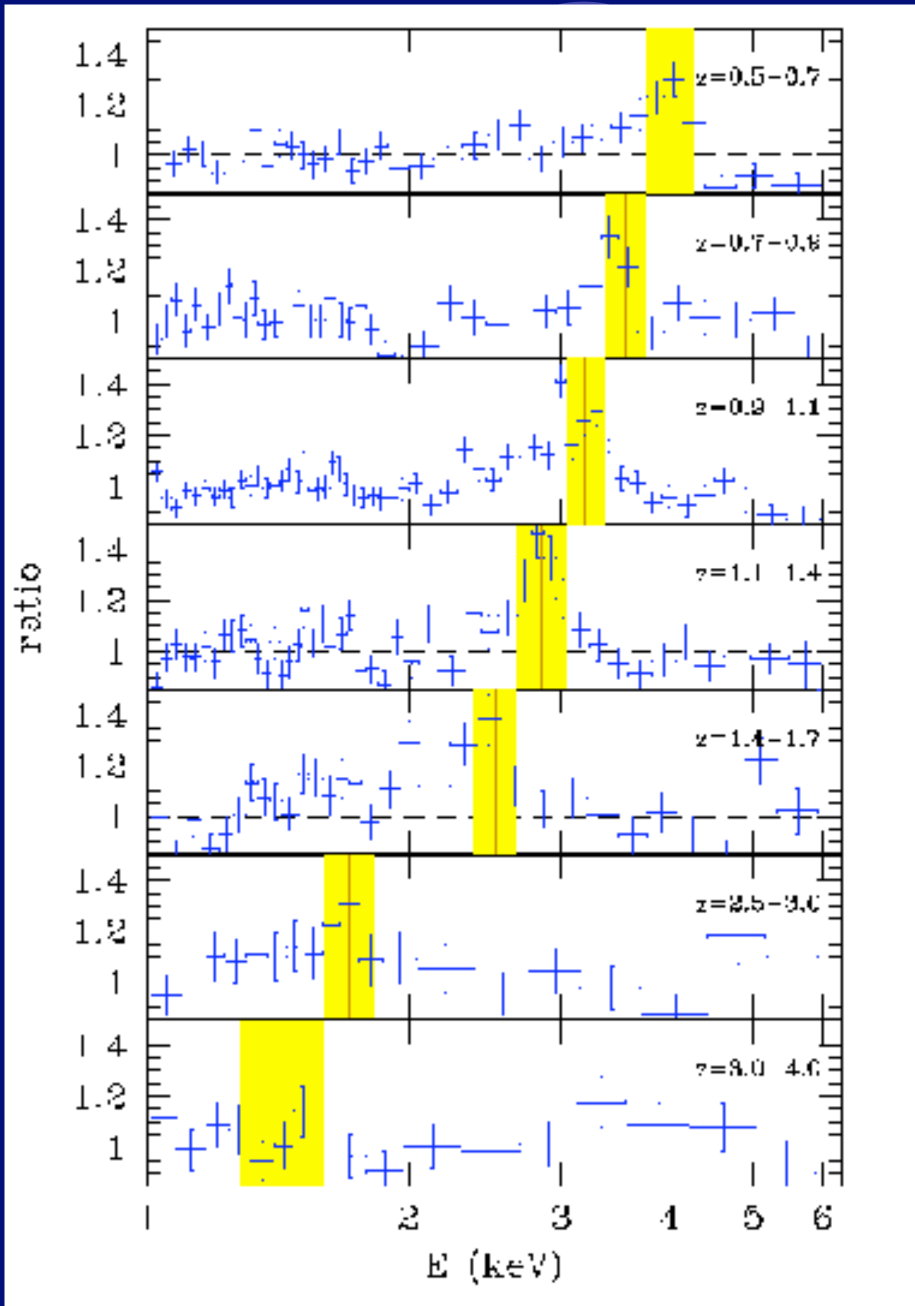


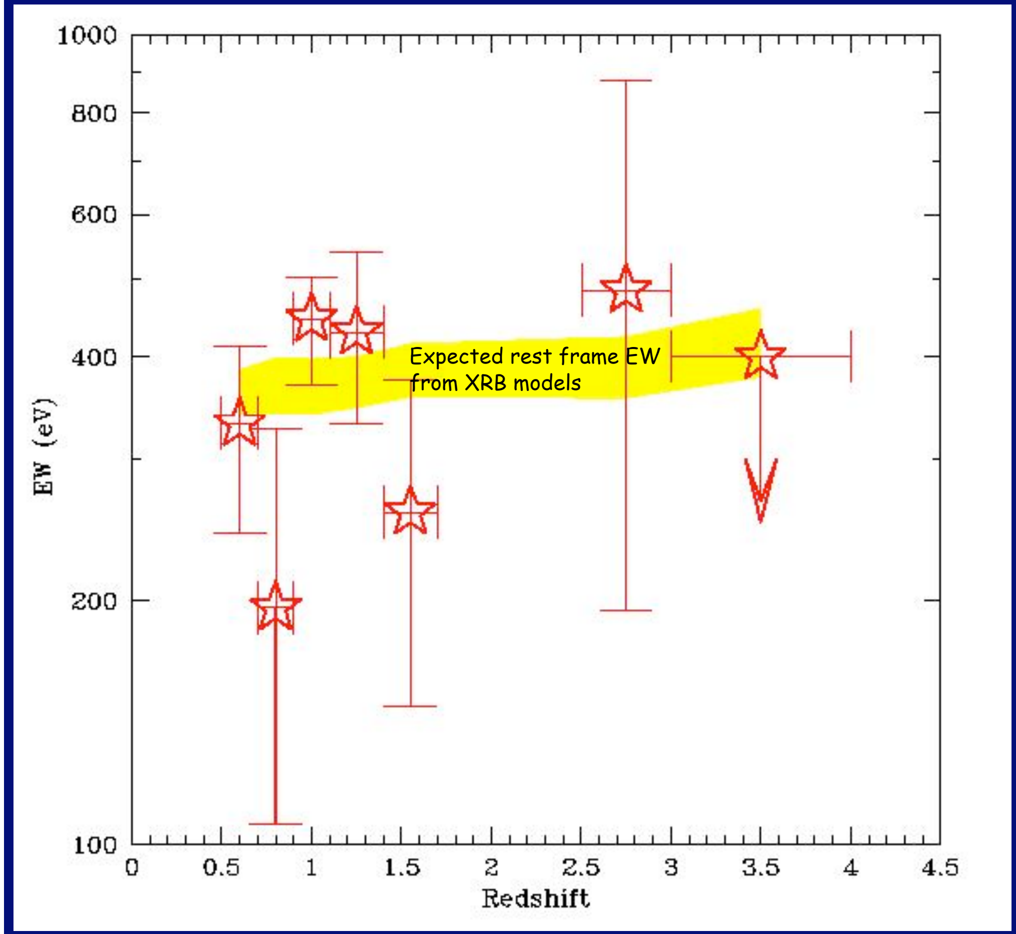


search for iron features over appropriate redshift bins: > 300 sources in **CDFS** and **CDFN** in the range z=0.5-4.

(Alexander et al. 2003; Giacconi et al.2002; Barger et al. 2003; Szokoly et al. 2004; Zheng et al. 2004)

- a **significant excess** above a power-law continuum is present at the position expected for the FeKalpha line

The (non) evolution of Iron up to z=2

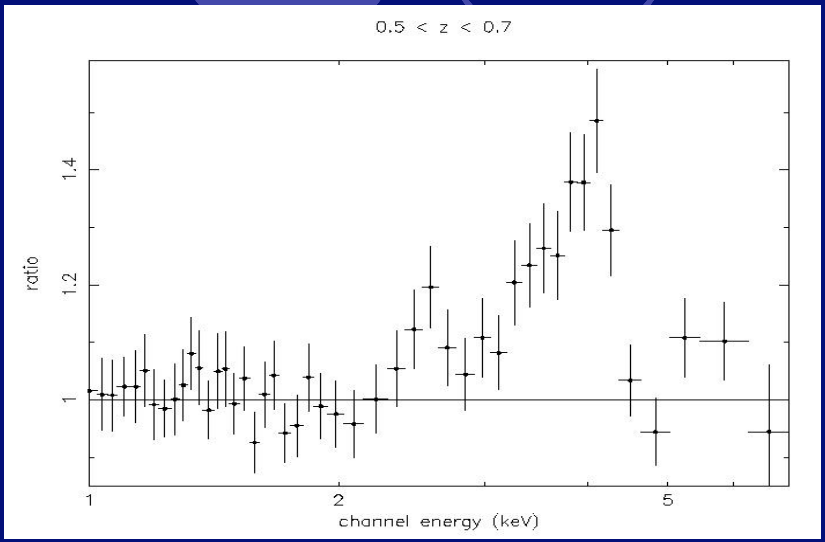


- The measured EWs are in agreement with simple pre-Chandra estimates based on XRB synthesis models

- About the same amount of iron is present around BH from z=2 up to z=0.5 → most of the iron was created before the Universe was about 2 billion years old

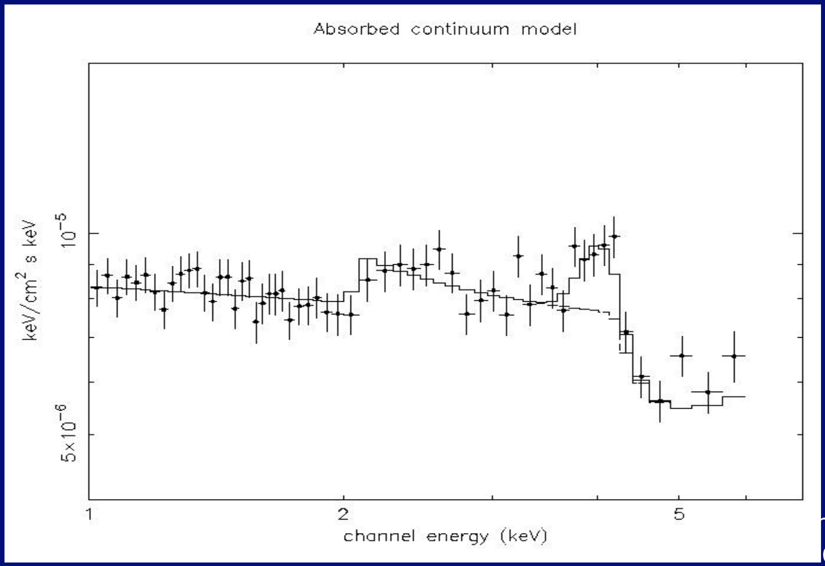
A close look into the line profile..

Comastri, Brusa & Gilli, 2007, astro-ph/0603139



Is a broad relativistic component common in all sources (see e.g. Streblyanaska+05)?

Stacked spectra of ~30 sources at z=0.5-0.7 in CDFS – broad/red wing present in the residuals



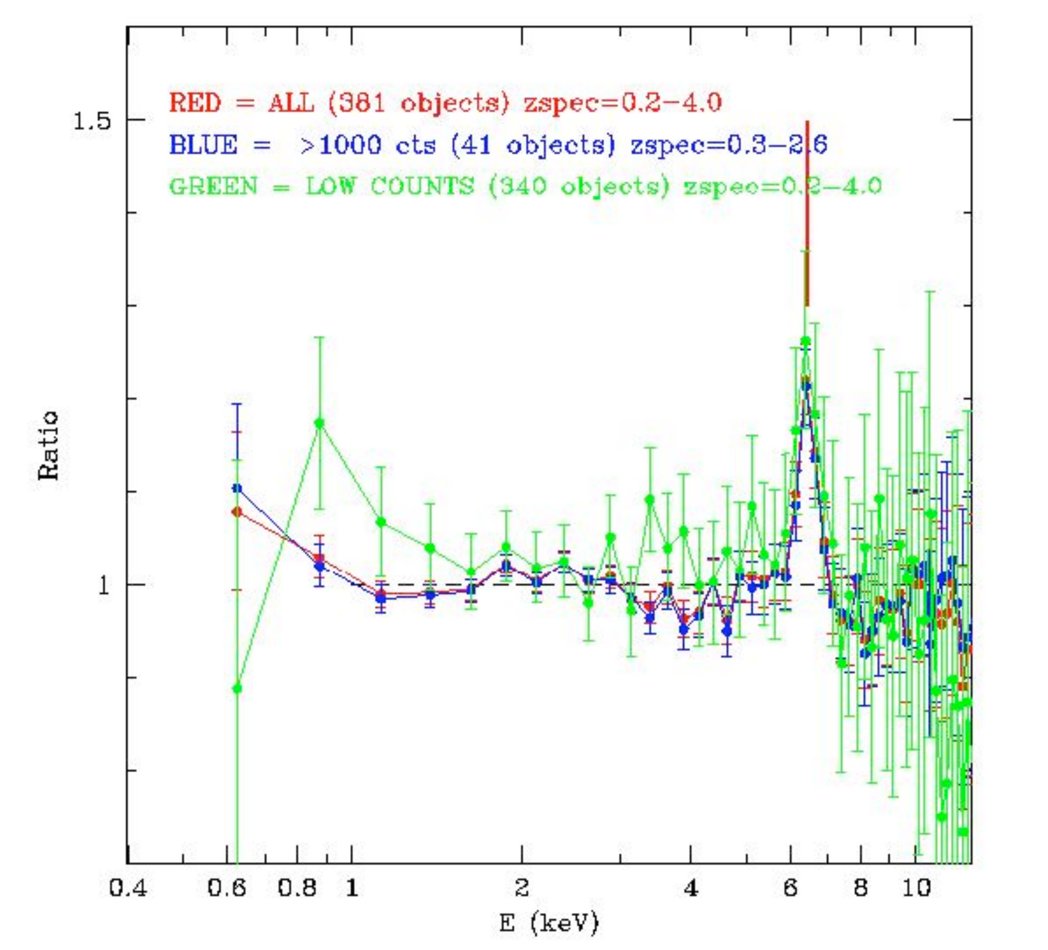
The effect of the continuum

The extended broad wing can be almost completely accounted for by the continuum predicted by XRB models in the same redshift bin

De-redshifting…

All CDFS+CDFN Sources with z=0.2-4.0

381 objects



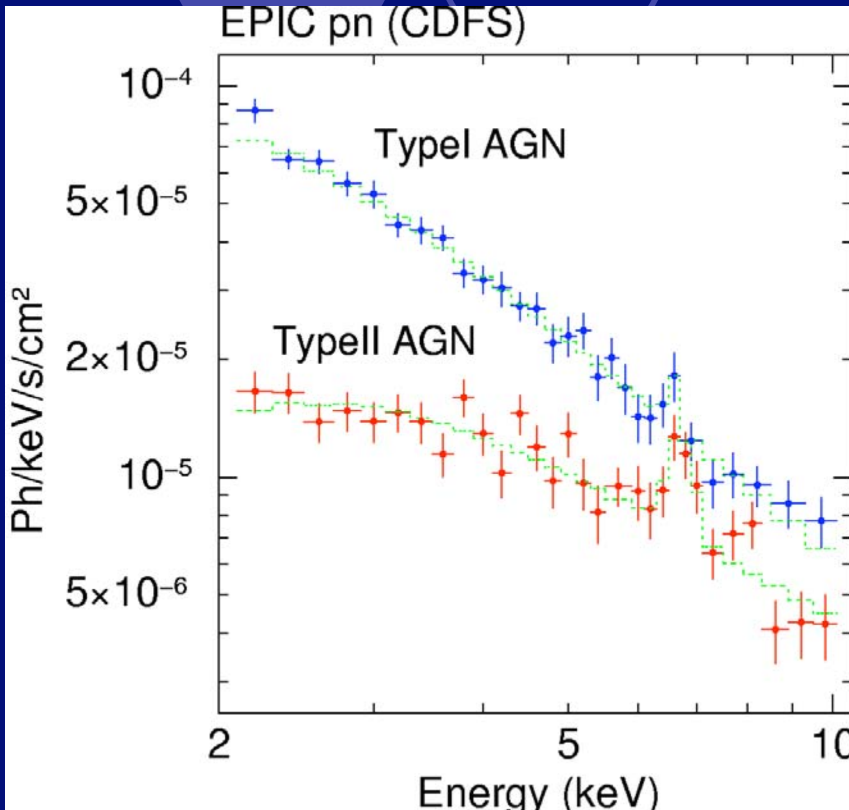
EW~150-300 eV

NO broad relativistic component..

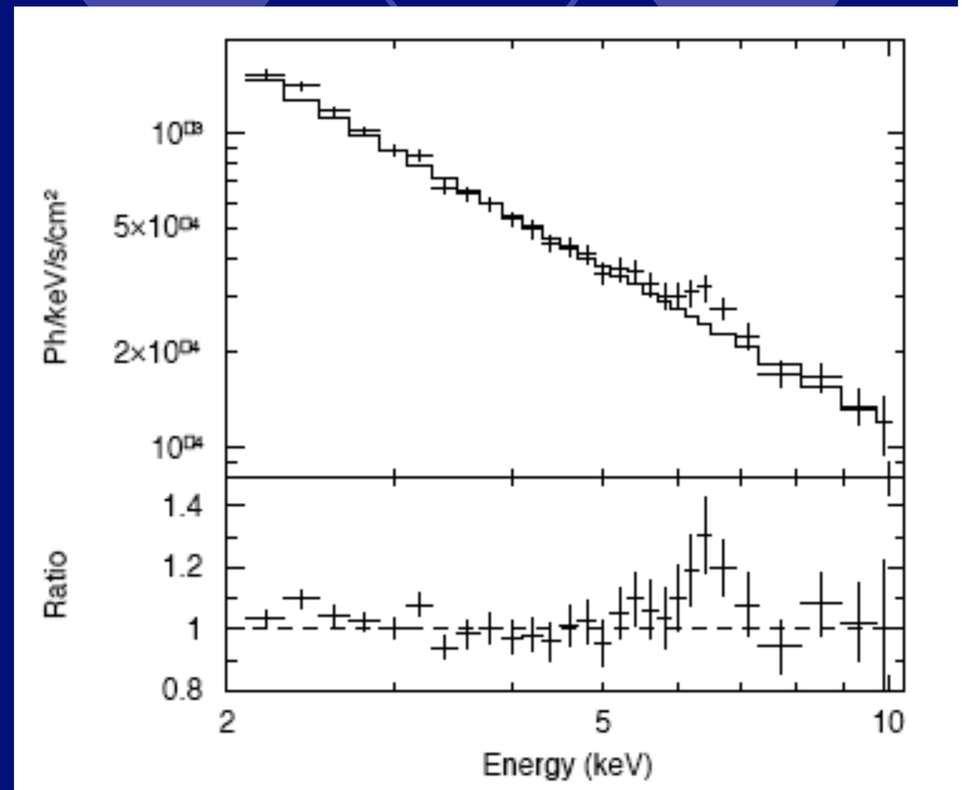
Work in progress

Stacking XMM data

Work in progress
(K. Iwasawa)



CDFS XMM



XMM-COSMOS

→Broad (~300 eV) but not relativistic line detected
(see also Longinotti et al. arXiv/0709.3268)

Summary

- Chandra stacking is a powerful tool to do science!
- Striking/important results mostly on the most obscured X-ray population → Chandra unveiled obscured accretion
- The Iron line footprint on XRB has been detected by Chandra; study of the line profiles deserves further investigations

Perspectives…

- Ongoing deep (e.g. 1Ms additional DDT time on CDFS) and large (e..g. CCOSMOS/EGS) Chandra surveys offer unique opportunity to exploit the stacking technique at its best

- Sinergies with NASA great observatories (Spitzer+HST) & Herschel

- Chandra will not be confusion/background limited up to 5-10 Ms…
  → 5-10 times better statistics than present, still lot of the Lx-z plan to investigate!
- XMM-Newton is not been pushed yet a the confusion limit in the 5-10 keV band
  → exploit deep XMM exposures for spectroscopy of most obscured sources

- Future: Con-X & XEUS !
  http://www.esa.int/esaCP/SEM1IQAMS7F_index_0.html
  http://www.mpe.mpg.de/~xeus

Same statistics obtained in average chandra/xmm spectra, but for single sources

The Cosmic X-ray Background (XRB)