The X-ray Background

- "In sharp contrast (to γ-ray astronomy), X-ray astronomy came as a complete surprise" (Boldt 1999)
- "Astronomy is replete with examples in which the most significant advances or the most astounding discoveries arose with the opening of new observational windows, partly by design and partly by chance".(Boldt 1999)
- The x-ray background is the convolution of these two ideas

Table 2. Historical Perspective: New Windows on the Universe: Cosmic Discoveries

EXPECTED	UNEXPECTED
An interstellar medium	A hot x-radiating plasma
Gamma-ray Astronomy	Gamma-ray bursts
Black holes	X-ray Astronomy
Neutron Stars	Pulsars
Gravitational radiation	Binary pulsar
Gravitational lensing	Dark matter
The Milky Way	Galaxy clustering
	Supermassive Black Hole Galactic Nucleus
Evolution	Radio Astronomy
	$\boxed{\text{Quasars}}$
	$\boxed{\text{Cosmic X-ray Background}}$
"Big Bang" relic Cosmic	
Microwave Background	A distortionless black body spectrum
Primordial gas in clusters	Iron K-line emission in clusters
Baryon Symmetry	Matter, matter everywhere
Extragalactic Cosmic Rays	Too energetic

There are ~15 papers with >300 citations on the XRB

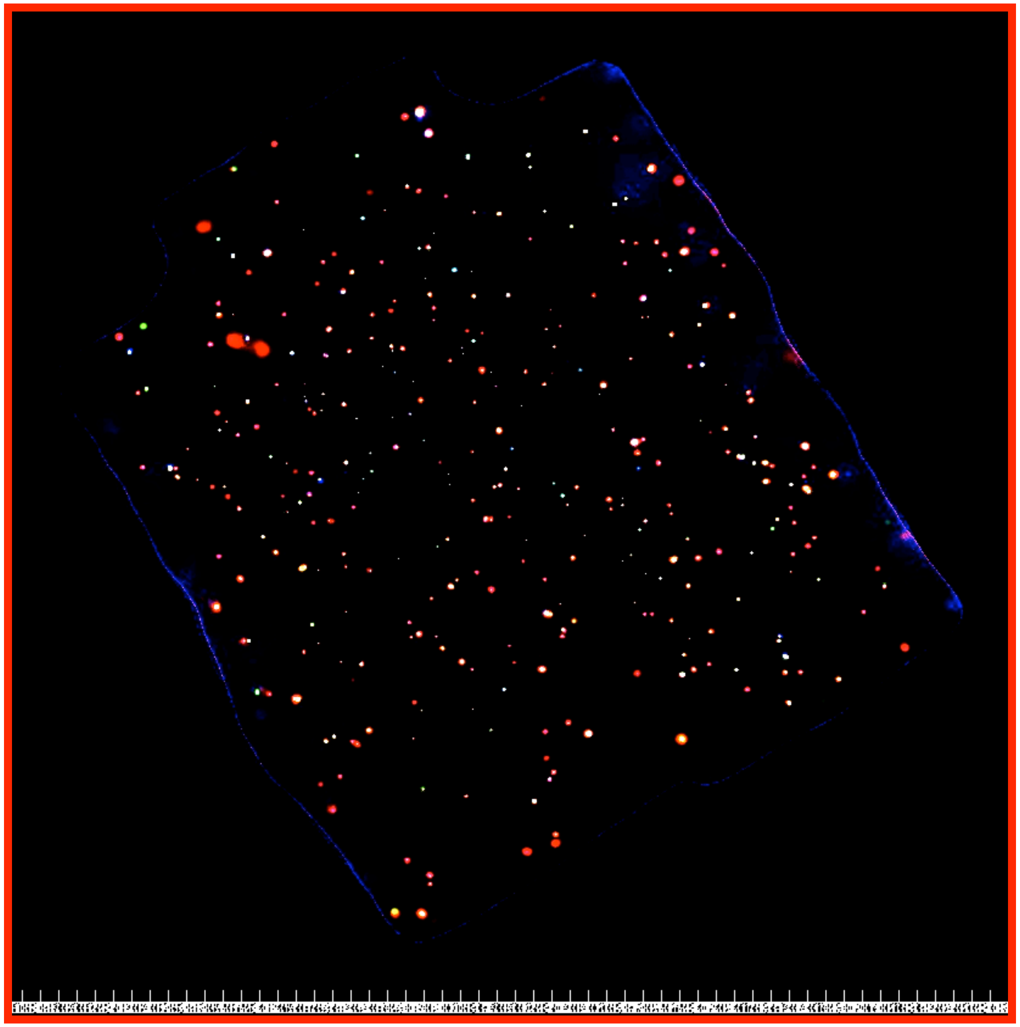
The XRB is the Sum of the The History of Active Galaxies

- Active Galaxies (AKA quasars, Seyfert galaxies etc) are radiating massive black holes with $L \sim 10^{8}\text{-}10^{14} L_{sun}$

- The change in the luminosity and number of AGN with time are fundamental to understanding the origin and nature of massive black holes and the creation and evolution of galaxies

- ~20% of all energy radiated over the life of the universe comes from AGN- a strong influence on the formation of all structure.

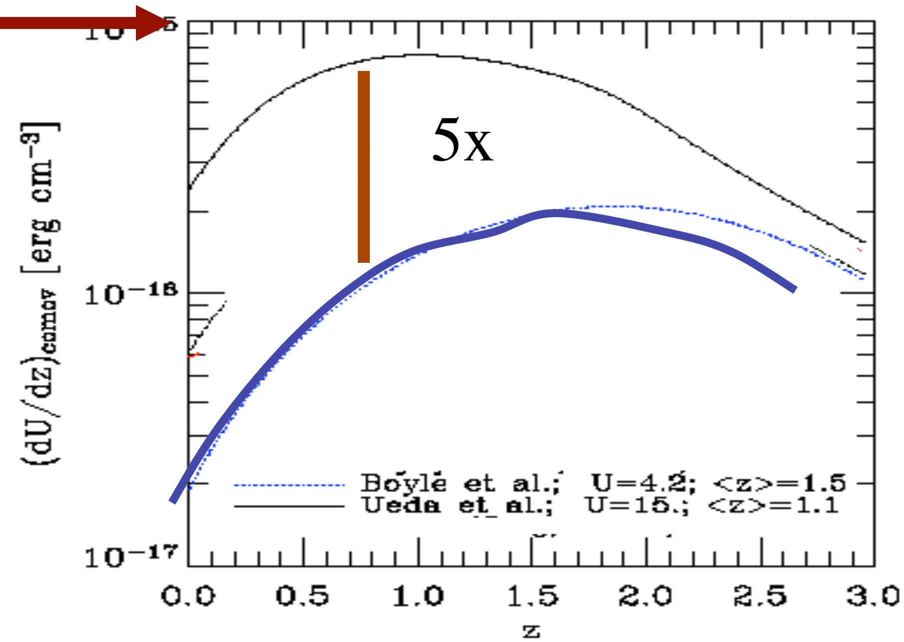
- **Chandra and XMM data have revolutionized our understanding of the number, luminosity and evolution of active galaxies from 0<z<4**



X-ray Color Image (1deg)
of the Chandra Large Area X-ray Survey-
CLASXS

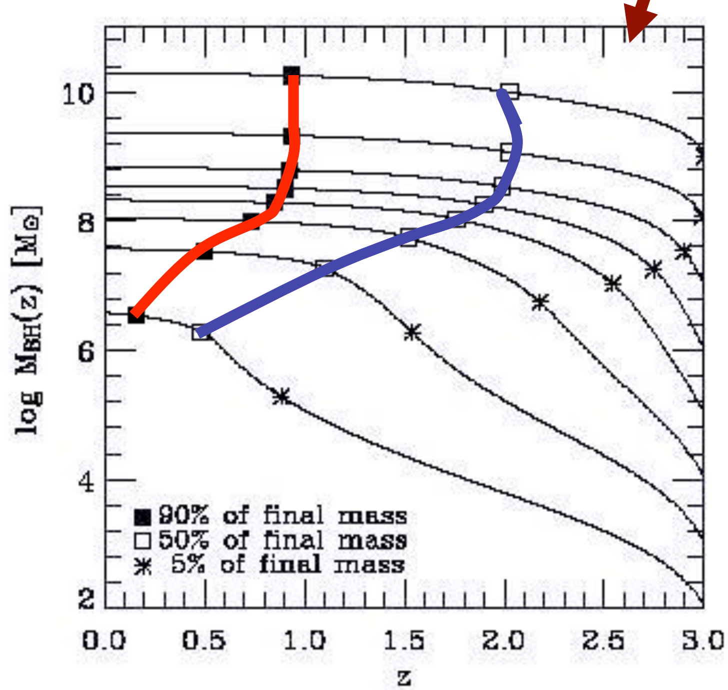
Comparison of Energy Densities and Evolution

- **Optical samples miss most of the energy radiated by BHs at z< 2**
- Most of the AGN luminosity is due to M~10 $^{7+/-1}$ M objects
- The x-ray data show that lower mass black holes evolve later and grow more than more massive objects.



Marconi et al 2004

When BHs get their mass



Accretion rate per unit time

Energy densities from AGN from Optical (---) x-ray (-------) surveys

Each line is the growth of a Massive BH vs z

What is the X-ray Background

- In the Astronomy and Astrophysics Encyclopedia Elihu said

"If the CXB is mainly due to AGN (i.e., not diffuse and not due to other discrete objects such as star-forming galaxies), then these sources must undergo substantial evolution in their luminosity whether or not spectral evolution is involved. As such, much of the CXB would arise from AGN at $z > 2$"

We now know, thanks to deep observations with the Chandra and XMM missions that there is strong luminosity evolution and weak evidence for spectral evolution. However the bulk of the background comes from $z \sim 1$ (this is probably most due to the Λ cosmology which Elihu did not know about at this time)

There are only two bands of the electromagnetic spectrum where the sky is dominated by a clearly isotropic extragalactic background. The most celebrated is the microwave band [1] in which resides the 2.7°K black body relic radiation cooled from an early stage of the expanding universe when its energy equivalent mass density exceeded that of ordinary matter. The other is the X-ray band [2] where we find a well defined component associated with more recent epochs in which subrelativistic matter dominates.

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What Did Elihu's Work Focus On

- Measuring the spectrum of the XRB (OSO-8 and HEAO-1)- the only satellite instruments designed to measure the 2-40 kev XRB
- Trying to relate the sources of the XRB to other astrophysical objects (T. Miyaji's and R. Shafer's thesis and work with C. Scharf and others on correlations, dipole, Compton-Getting effect, fluctuations)*
- Theory: what could these objects be (work with D. Leiter)

What was of interest to Elihu?

In a review article from 1995 he said "The CXB is particularly fascinating because it gives us a remarkable precise "total answer" about the extragalactic x-ray sky. Of foremost importance is that it has a definite characteristic energy (40 keV) in the sense that the measured background radiation may be represented by a simple expression… "

•Elihu's work and that of Giaconni and Collaborators was almost orthogonal: Elihu did not 'count and identify sources'

A Career Long Interest

- Elihu participated in over 115 papers involving the x-ray background from 1969 1969 Nature 224..Boldt, E. A.; Desai, U. D.; Holt, S. S.; Serlemitsos, P. J.**The 2-20 keV X-ray Sky Background**

To 2001

- 2001AIPC..599..MacDonald, Daniel R.; Gruber, Duane E.; Boldt, Elihu A. Measurements of fluctuations in the hard X-ray background with RXTE

- With ~1400 citations (the Marshall et al HEAO-1 paper on the spectrum of the XRB has 6 citations in 2009 !)

2–20 keV X-RAY SKY BACKGROUND

E. A. BOLDT, U. D. DESAI, S. S. HOLT, and P. J. SERLEMITSOS
NASA/Goddard Space Flight Center, Greenbelt, Md., U.S.A.

Abstract. The diffuse background of 2–20 keV X-rays over a band of the sky extending from Scorpius to the North galactic pole is found to be isotropic to within 5%, with a spectrum given by

$$10.3\,E^{-n}\ \text{photons}/(\text{cm}^2\text{-sec-sr-keV}),$$

where $n = (1.35 \pm^{0.07}_{0.10})$.

A comparison with spectra at higher energies indicates that the lower energy spectrum is flatter, corresponding to an apparent unit change in spectral index within the band 20–80 keV. A spectral break in this energy region has been discussed in connection with the collisional energy loss lifetime for metagalactic protons that radiate X-rays via inverse bremsstrahlung collisions with the ambient electrons of the intergalactic medium (Boldt and Serlemitsos, 1969; Hayakawa, 1970).

Taken together, all these results suggest a change in spectral index of about unity within the interval 20–80 keV.

This 1969 paper had the right spectral form and normalization to the XRB spectrum- an issue still argued about 40 years later
- the latest Chandra value is a CXB power law normalization (for photon index 1.4) of 10.9 photons cm^{-2} s^{-1} keV^{-1} sr^{-1}

Where are We Today

- Integration of deep sources counts in the 1-6 keV band have resolved a large fraction of the background
- The cottage industry of modeling the evolution of sources + contribution to the XRB (Setti and Woltjer 1989, Gilli et al 2008) is quite sophisticated but
- has numerous degeneracies in the parameters of those models (Triester, Urry, Virani)
  - involving the distribution of column densities, the number of Compton thick objects and the exact evolutionary rate of AGN

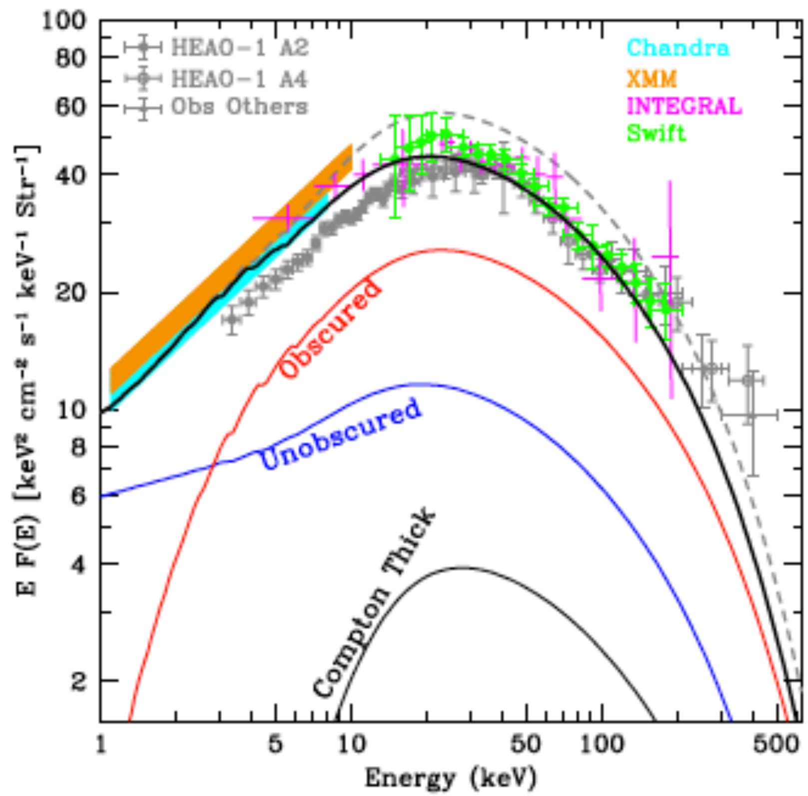
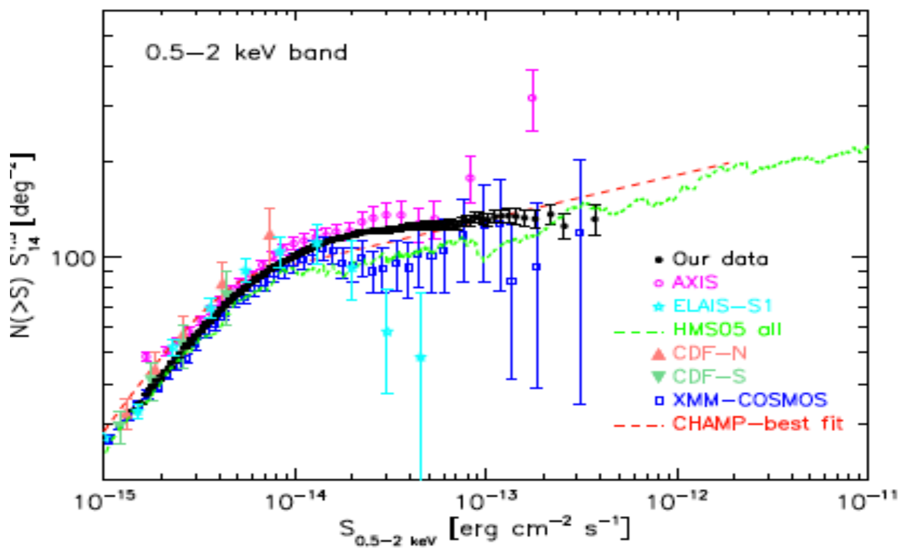
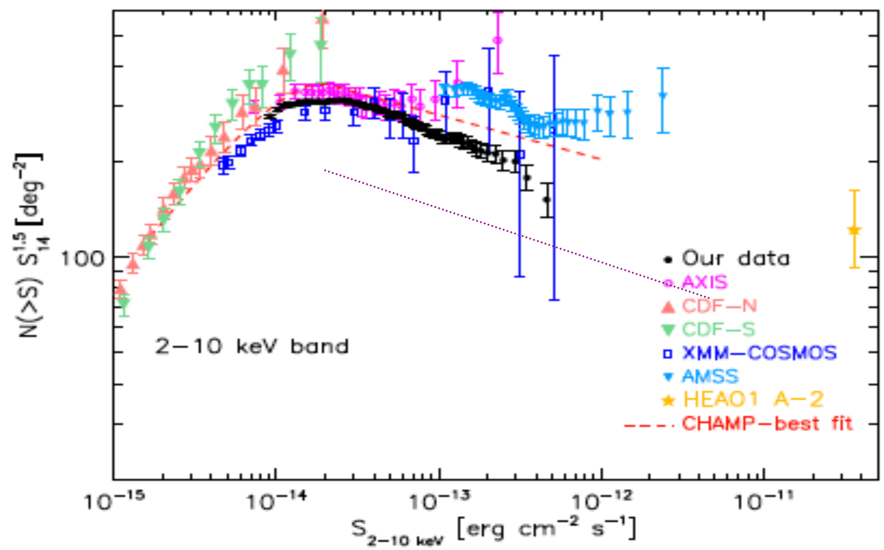


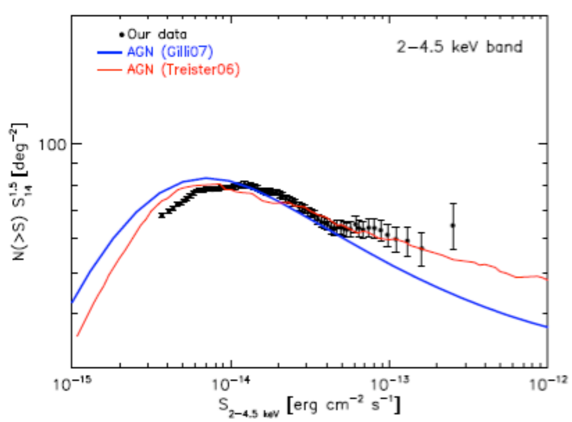
FIG. 5.— Observed spectrum of the extragalactic X-ray background from HEAO-1 (Gruber et al. 1999), Chandra (Hickox & Markevitch 2006), XMM (De Luca & Molendi 2004), INTEGRAL (Churazov et al. 2007) and Swift (Ajello et al. 2008) data. The *dashed gray line* shows the XRB spectrum from the AGN population synthesis model of Treister & Urry (2005), which assumed a 40% higher value for the HEAO-1 XRB normalization. The *thick black solid line* shows our new population synthesis model for the XRB spectrum; the only change is the number of CT AGN, which is reduced by a factor of 4 relative to the number in Treister & Urry (2005). *Red*, *blue* and *thin black* solid lines show the contribution to this model from unobscured, obscured Compton thin and CT AGN respectively.

Source Counts Well Determined from 0.5-10 Kev over a factor of 10^5 in flux- but still disagreements!

S. Mateos et al.: High precision X-ray logN-logS distributions: implications for the obscured AGN population







What is the cause

- cosmic variance,
- Data analysis techniques
- calibration

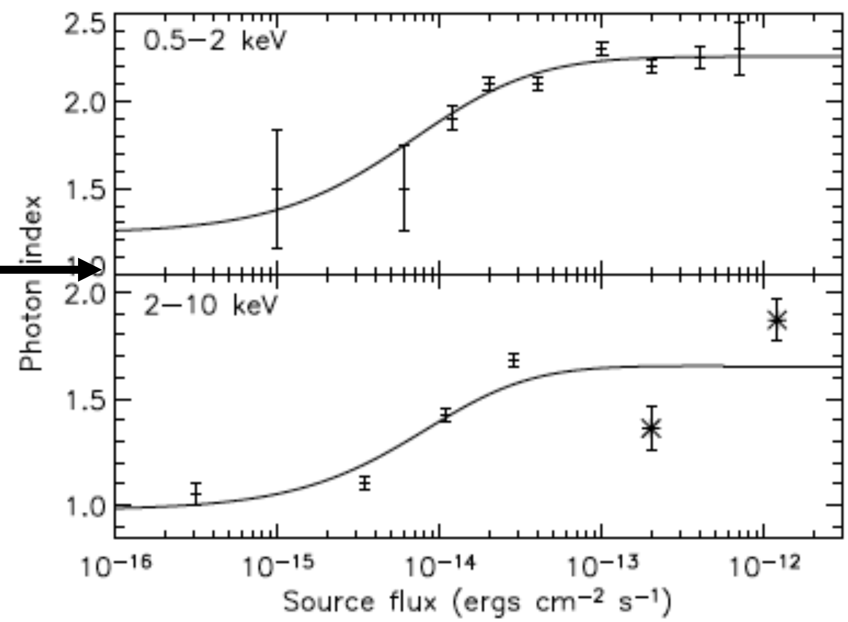
Fig. 13. Comparison of the normalised source count distributions in integral form in the 0.5-1 keV, 1-2 keV, 2-4.5 keV and 4.5-10 keV bands with the predictions from the synthesis models of the CXRB of Treister & Urry (2006) and Gilli et al. (2007): AGN only (solid lines), AGN+clusters+stars (dashed lines). Error bars correspond to 1σ confidence.

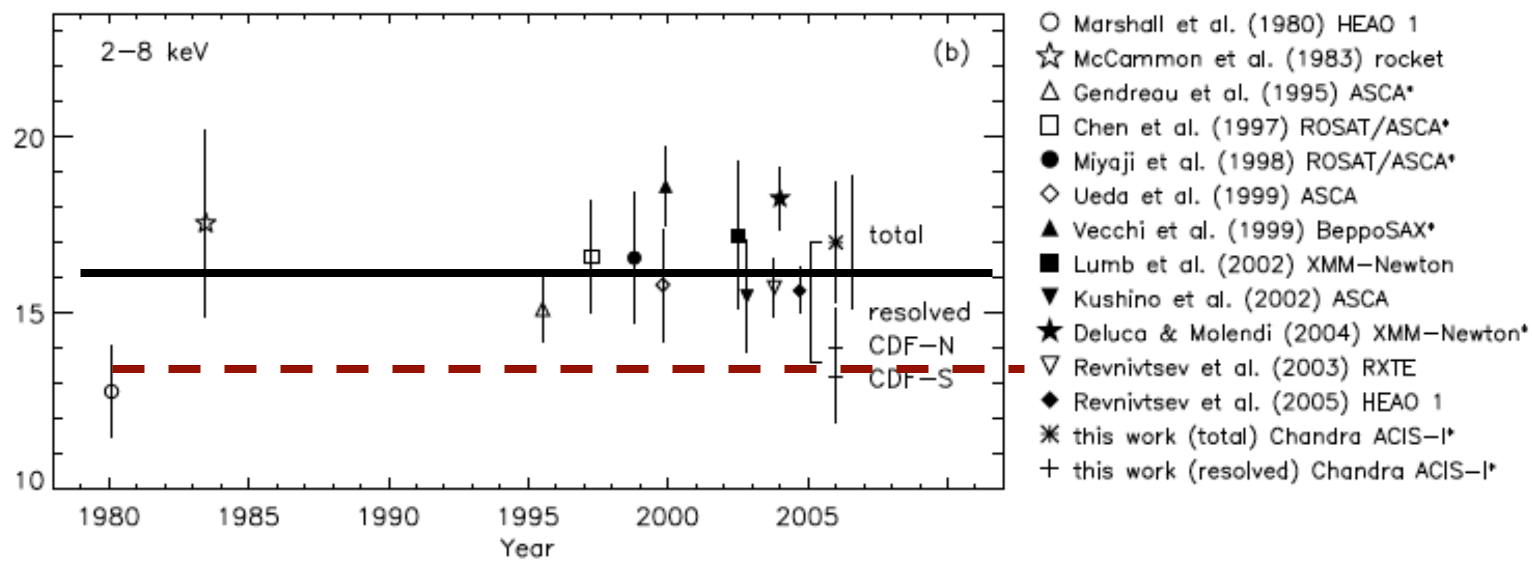
Source Spectrum Changes with Flux

- Elihu coined the term 'spectral paradox': that is the spectrum of individual bright sources did not look like the background
- This paradox has 2 resolutions

a) The spectrum of sources changes with flux

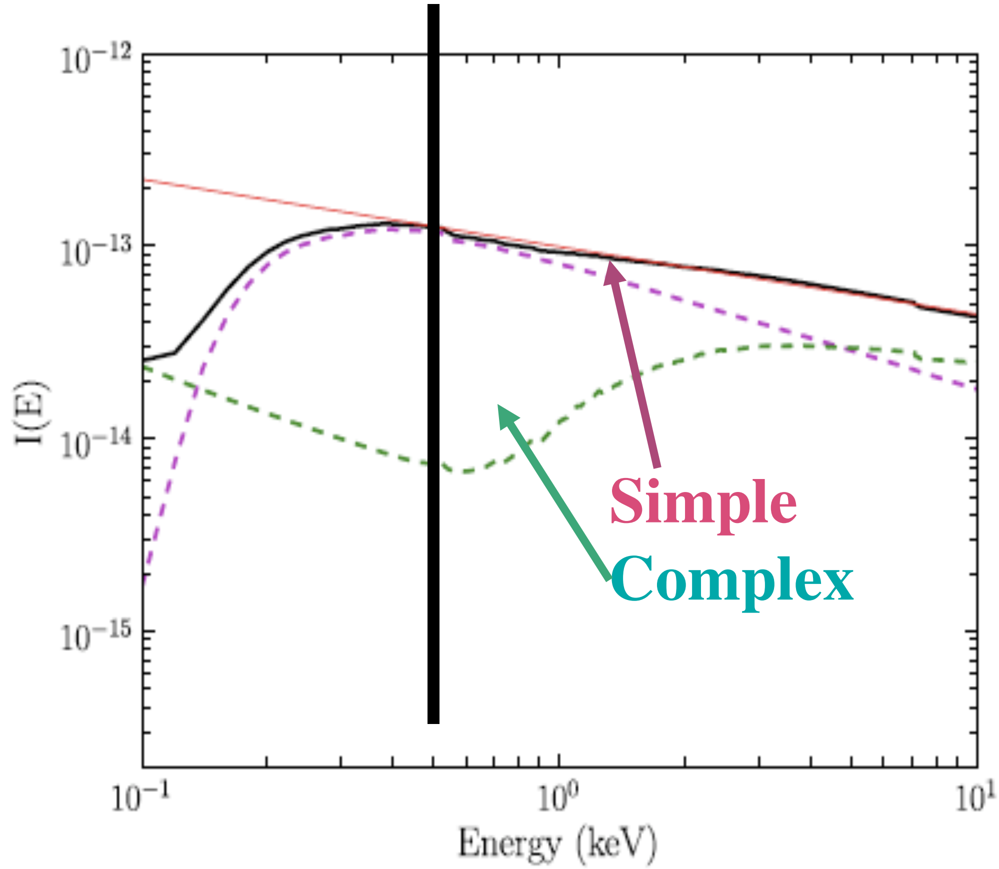
b) Sources that are bright at 2-10 may not be representative of the 2-40 kev population (absorbed sources)- use hard x-ray sample (Swift)





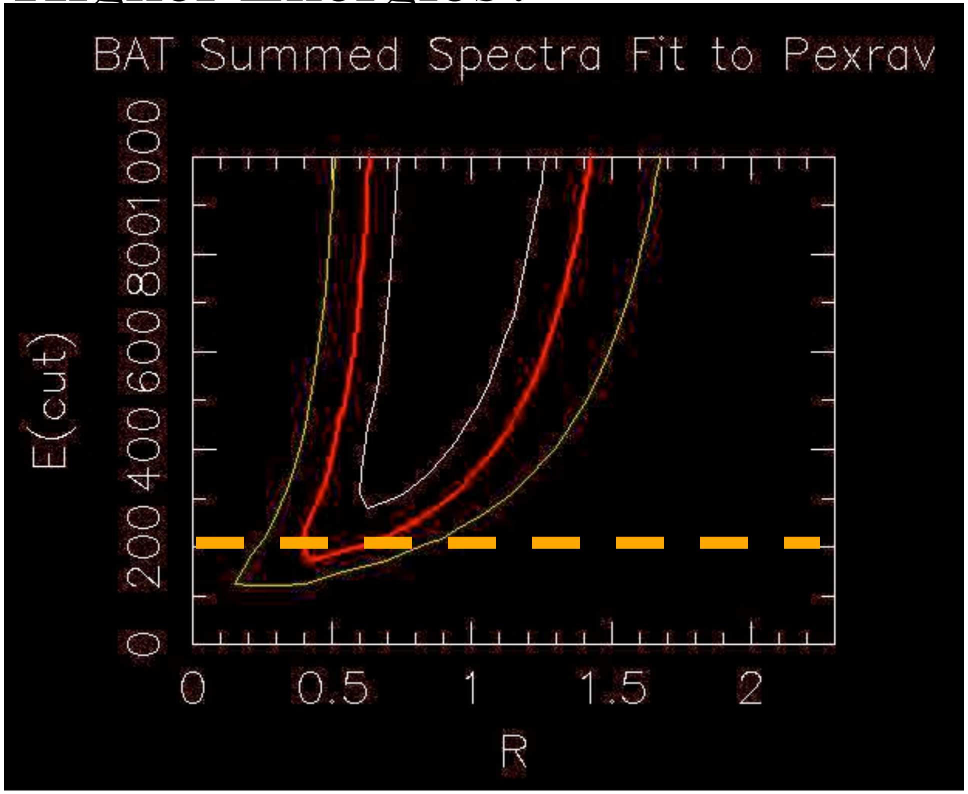
Origin of the X-ray Background

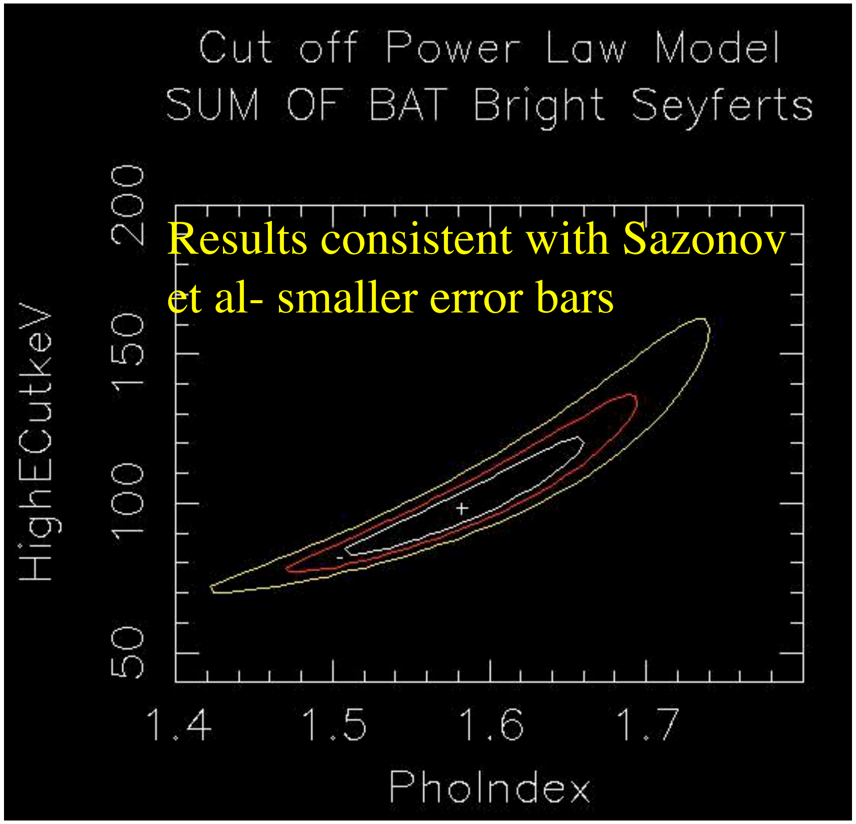
- Sum of the flux weighted .5-10 kev spectrum of the BAT sources (black) - well described by a Γ=1.4 power law just like the XRB (Winter et al 2009)
- Nature has 'conspired' to make the sum of the complex and 'simple' sources 'just so' *for a hard x-ray selected low z sample*



What about the Higher Energies?

- There are a wide variety of cutoffs
- The population is consistent with a ***reflection model*** with R~1, Γ ~2 $E_{(cut)}$~>200 keV OR
- *cutoff powerlaw* with Γ~1.6 and $E_{(cut)}$~100 kev OR
- ***broken PL*** Γ_1 ~1.75, Γ_2 ~2.2 and E_B~33





These results are **not** consistent with the spectrum of the XRB- UNLESS the median redshift is ~1; $E^{obs}_{(cut)}$~$E_{(cut)}$/(1+z)- slope maybe too steep in either the broken PL or cutoff PL model fits

Effect of Compton thick objects appears to be small

What about Blazars?

- Below 100 keV Blazars are not important but at E> 200 kev Blazars are a major contributor to the background

(Ajello et al 2009)

- The greater the blazar contribution, the less needed from Compton thick AGN (factors of 2-3 reduction compared to models without Blazars)

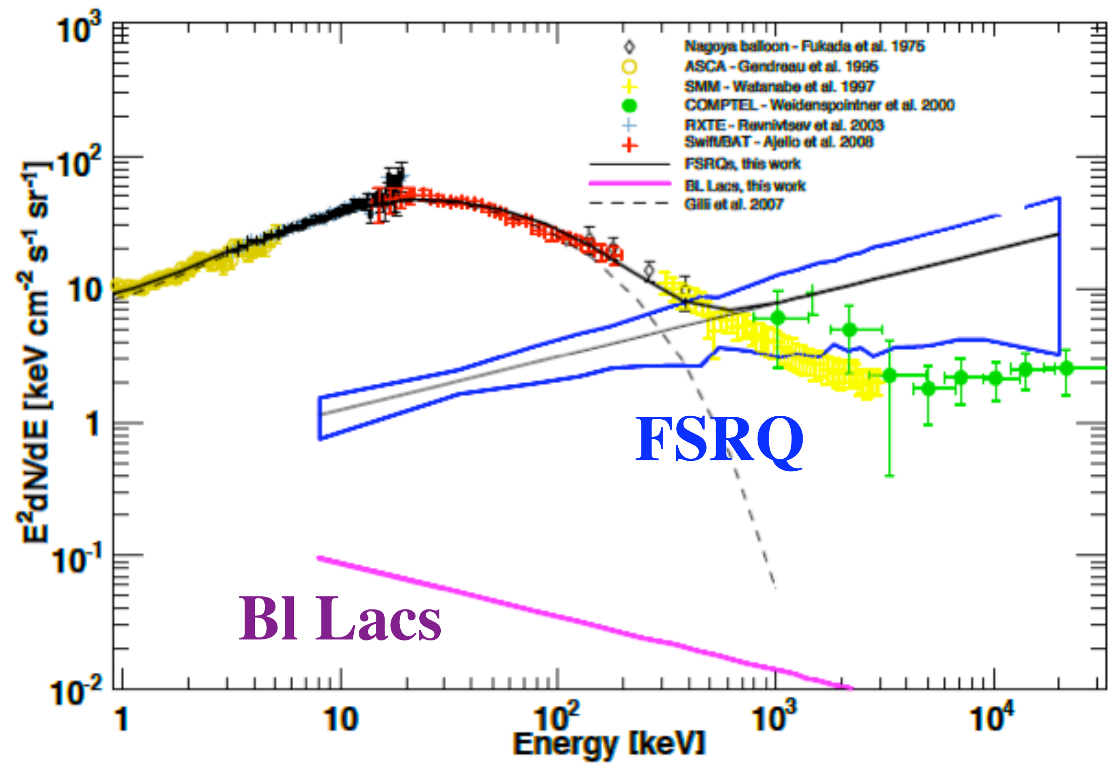


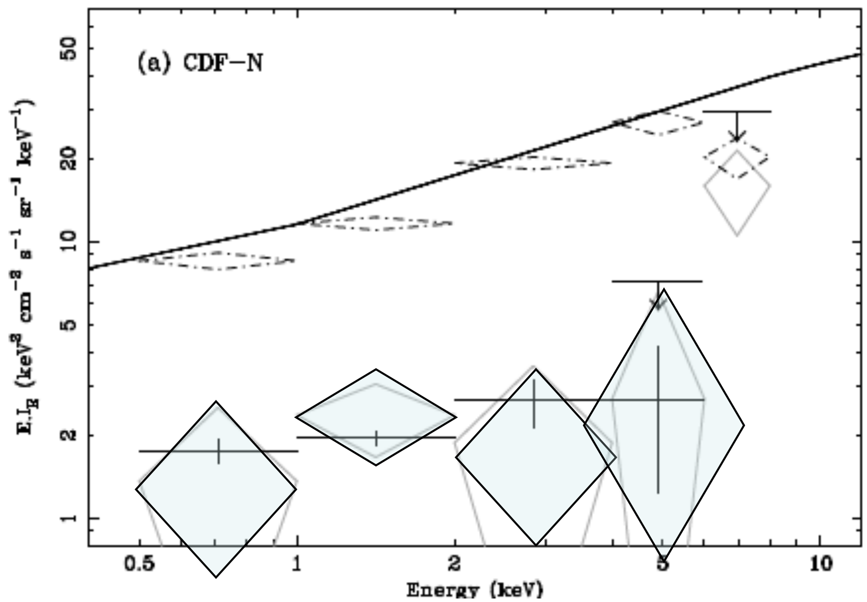
Fig. 15.— Spectrum of the CXB and contribution of the FSRQs (blue region). The

What is the rest of the background due to?

- at E>6 kev ~30-40% of the XRB is not resolved in the Chandra deep fields

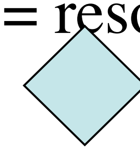
- What about E>6 keV?

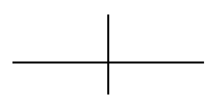
1) Not luminous obscured QSO (Steffen et al 2007) utilizing stacking techniques and mid-IR 24μ surveys
2) Stacking of very faint optical sources may do it- what are these??



Solid line =XRB

Dotted diamonds= resolved flux

Missing flux 

 flux in stacked optical objects in HDF

What new was required

- Elihu postulated the existence of new class of objects - 'Primordial AG or precursor active galaxies' - Eddington Limited objects at high z
- We now do not require such objects but may require the existence of
  - Compton thick AGN

A class of objects that was not postulated during the 1990's when Elihu did his theoretical modeling

Also the introduction of Λ cosmological models changes the luminosity function and its evolution significantly

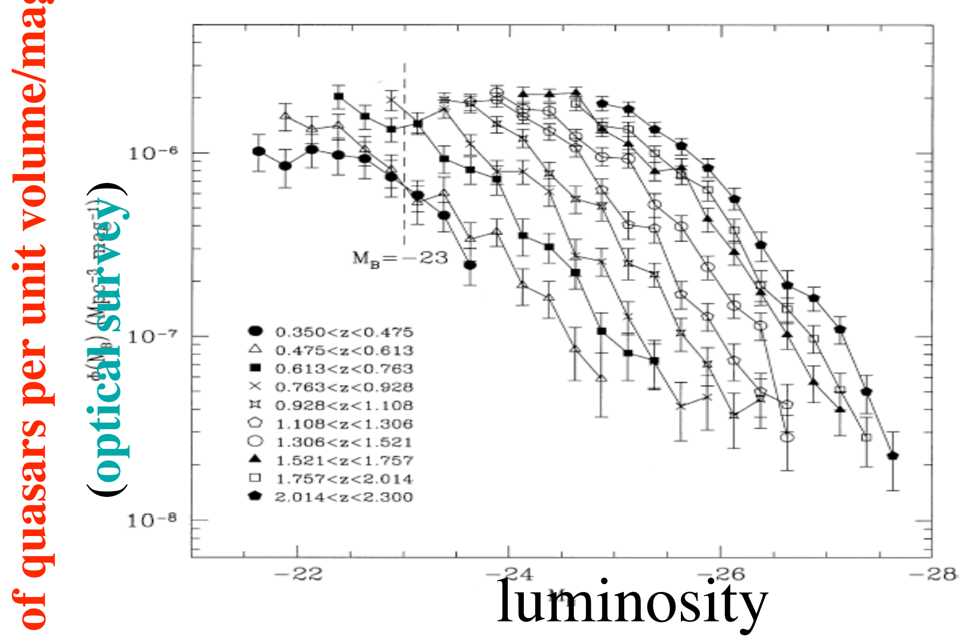
Optical Quasar Evolution

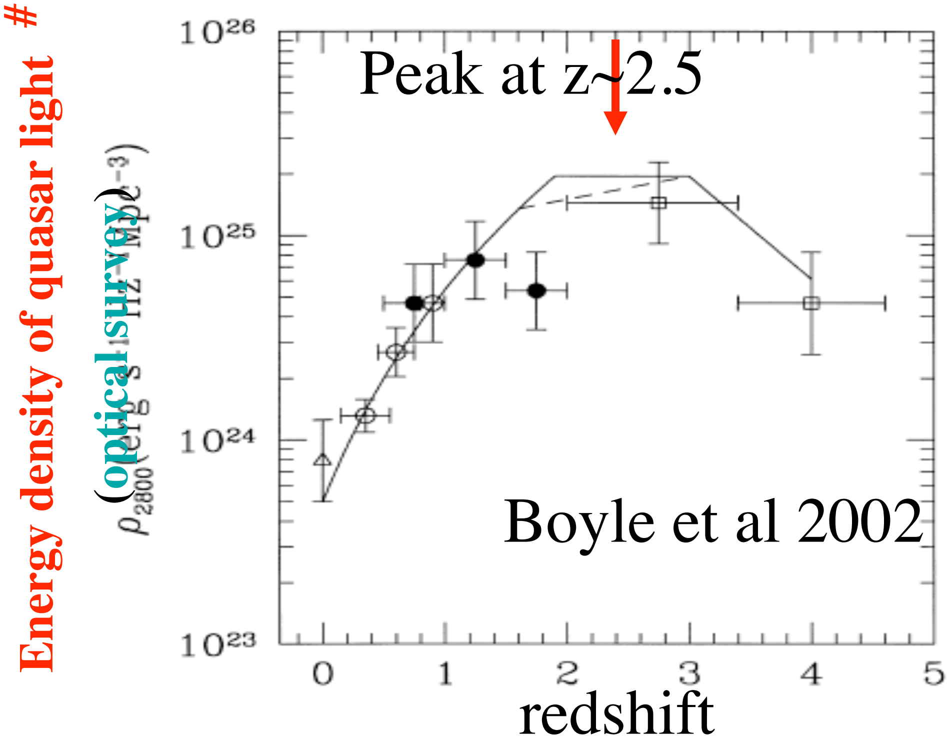
- Historically AGN were found in the optical band by a variety of techniques
  - Presence of strong very broad (1-10,000km/sec) optical and UV emission lines (Broad line objects)
  - The presence of a bright, semi-stellar nucleus (Quasar)
  - Variability of the nucleus
  - "Unusual" colors of the nucleus
  - Optical counterparts to radio source
- Large numbers were found out to z~6
- Since the late 1960's (Schmidt)

  "well known" that quasars were much more numerous and luminous in the past.

Thus quasars were thought to be created in the early universe.

Many theories were developed to explain this.





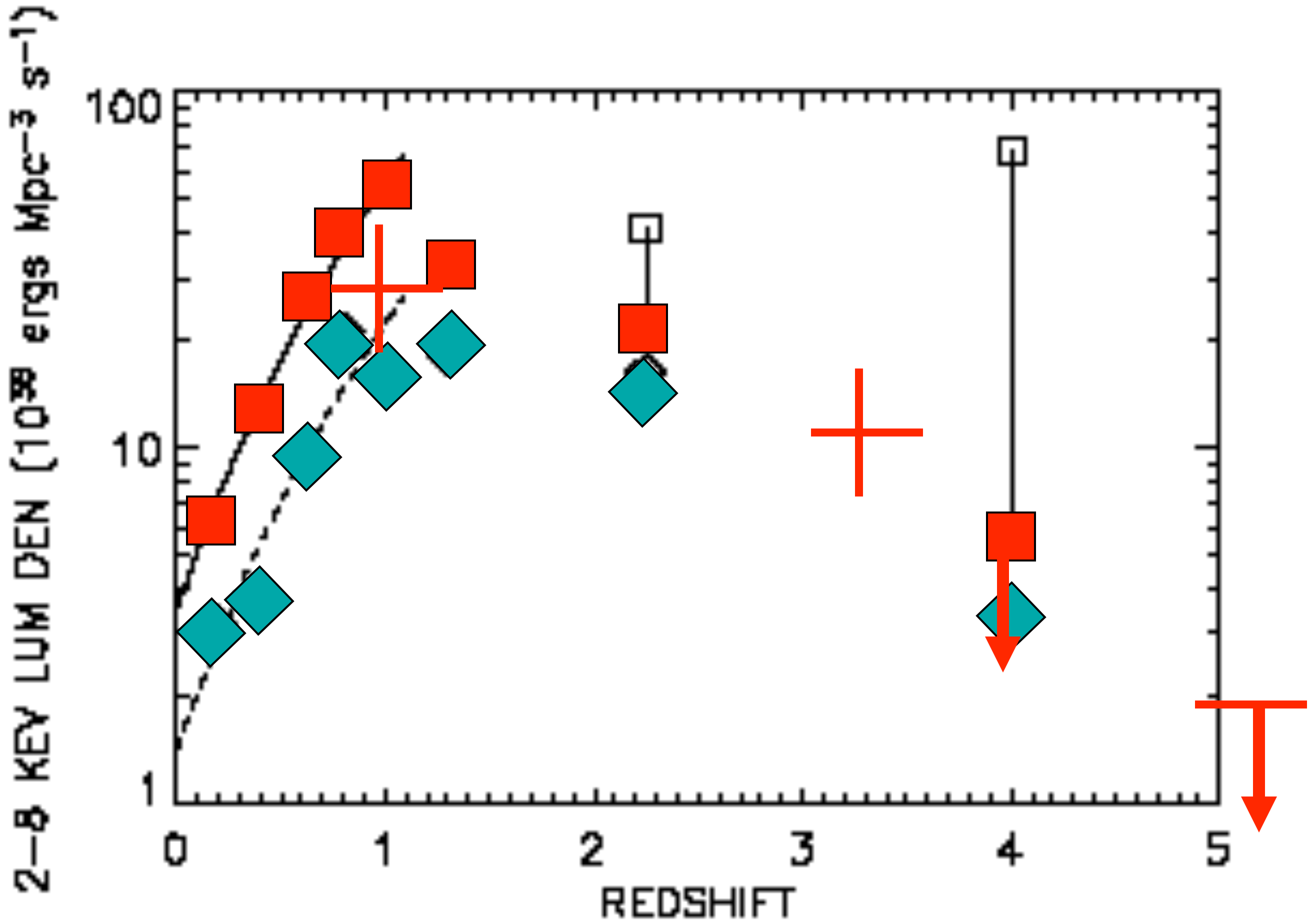
The X-ray Luminosity density drops at

- Even including upper limits there is less energy emitting per unit volume at z>1

Barger et al 2004

Similar results from Ueda et al 2003, Marconi et al 2004 Hasinger et al 2003 Fiore et al 2004

Upper limit at z~5.8 Moustakas and Immler 2004; points at z~3 and z~1 Nandra et al Also Lehman et al 2004



type I AGN, all objects

Open box- assigning all objects without a redshift to to redshift bin