The Cosmic X-ray Background measured with BeppoSAX PDS and its consequences

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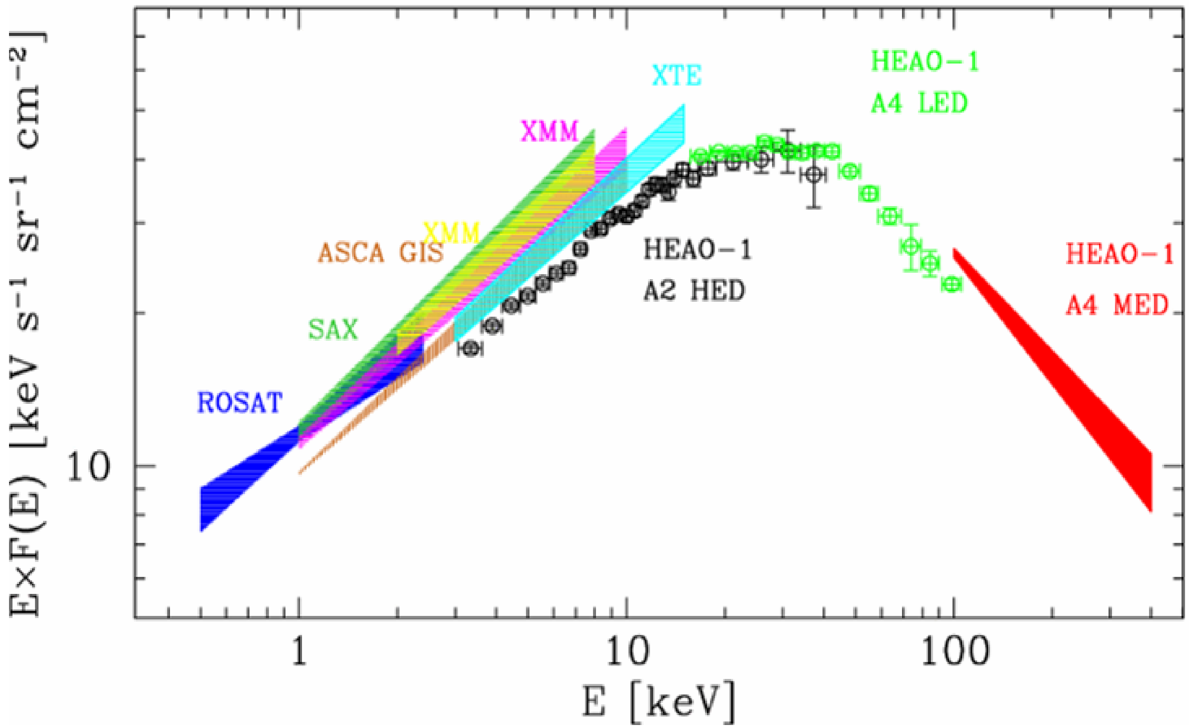
The paper (Frontera et al. 2007) is published in ApJ, Sept 1, 2007 issue, Vol. 666, p. 86

See also News&Views by Y. Ueda in Nature Physics, issue of 2 July 2007

Scientific case

- The CXB is mainly due to the integrated emission by AGN powered by SBHs:
  - At low energies (≤2-3 keV), optically bright quasars and unobscured Seyfert galaxies, dominate;
  - At high energies (>10 keV) obscured AGNs, still not singled out (only few), are expected to be responsible for the bulk of CXB;
- The size of the obscured AGN population can be estimated from the CXB intensity,
- But ...

Which is the real CXB intensity level?



- At low energies (2-10 keV), power-law shape with:
  - photon index well constrained (1.4);
  - intensity very uncertain (up to 40%).
- At high energies (>20 keV), the most reliable results come from HEAO-1/A2-A4 (Gruber 1999). In 3-60 keV:

$$I(E) = 7.877 E^{-0.29} \exp(-E/41.13) \ \ keV/cm^2 s \, keV \, sr$$

* MANY AUTHORS ASSUME the CXB spectrum obtained with HEAO-1 to be:

- correct in its shape;
- underestimated in its intensity.

Goal of our measurement:

• to establish whether the renormalization of the CXB intensity is justified at the emission peak;

• to constrain the size of highly obscured AGNs and to infer the presence of other source populations/diffuse components (e.g., WHIM).

The PDS aboard BeppoSAX ('96-'02)

➢ Energy passband: 15-200 keV with high detection efficiency;

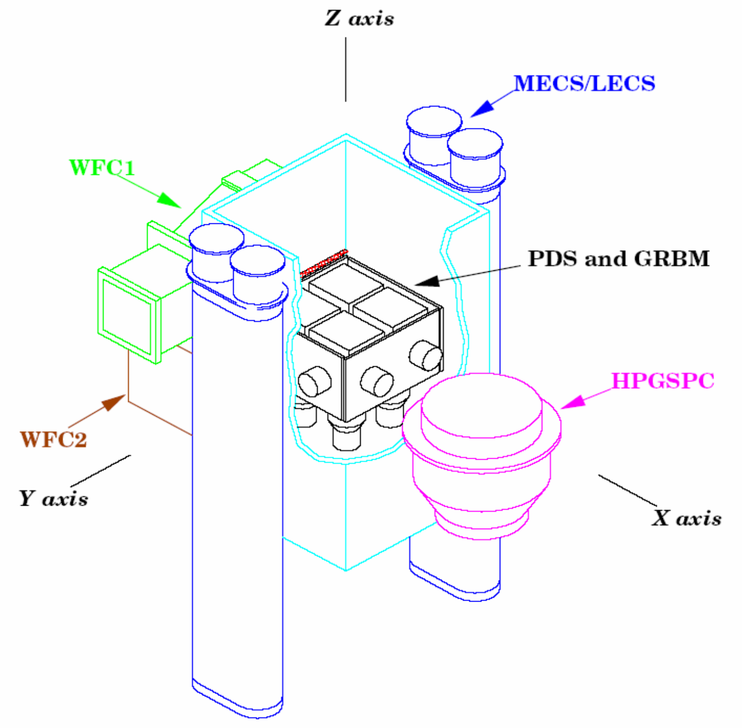
➢ Two independent rocking collimators to monitor both target and BKG (ON, -OFF, +OFF);

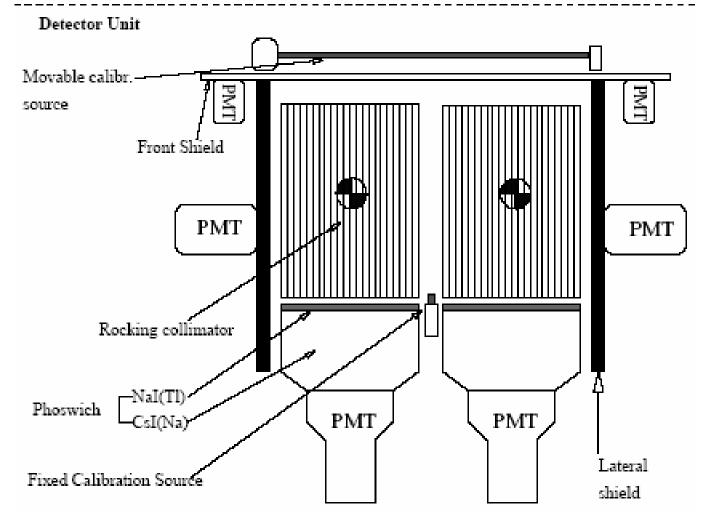
➢ FOV: 1.32 deg (hexagonal) tested in flight with Crab;

➢ BKG: very stable and low;

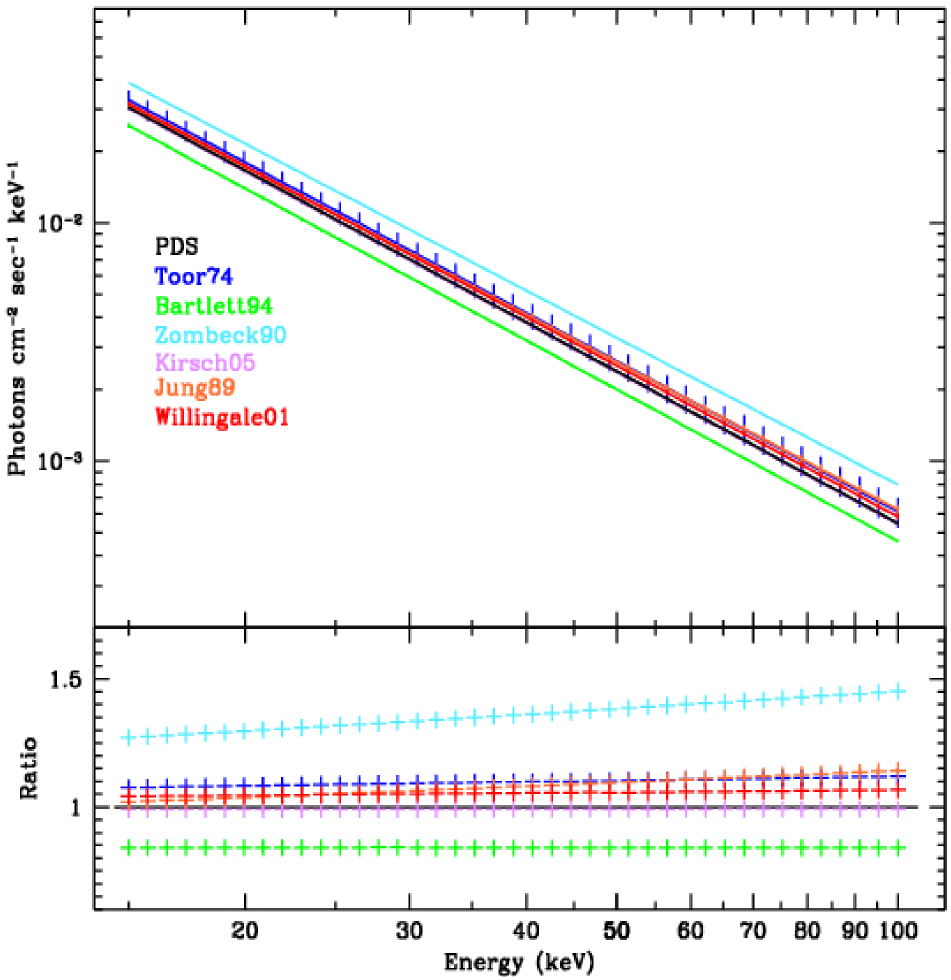
➢ Automatic gain control;

➢ Efficiency and spectral determination capability tested many times with Crab.





Test of the PDS calibration with Crab



Crab with SAX/PDS

- Fit with a power law model:

  <Γ> = 2.121±0.001

  <N> = 9.54±0.01

  χ^2/dof =25.66

2. Fit with a broken PL:

   $\langle \Gamma_1 \rangle$ = 2.113±0.001

   $\langle \Gamma_2 \rangle$ = 2.198±0.005

   <Eb> = 74 ± 2 keV

   <N> = 9.39±0.02

   χ^2/dof =17.1

→ 1% systematic error in response function

Measuring the unresolved CXB spectrum

- What is requested:
  - Blank sky fields;
  - Knowledge/removal of the intrinsic instrumental background B_{in}.

- Various methods followed for estimating/removing B_{in}:
  - Using 2 different FOVs (HEAO-1 A2):
  - Shielding the FOV with a shutter (HEAO-1 A4);
  - Using the background level outside the FOV (XMM/Newton)
  - Using the Earth-sky pointing method (EPM) (e.g., SAX/MECS, RXTE/PCA);

- We have adopted the EPM (PDS FOV << Earth width).

Sky-Earth pointing method

Blank sky field spectra $v_B^{sky}(E) = [v_{in}^{sky} + v_{CXB}]$

Earth pointing spectra $v_B^{Earth}(E) = [v_{in}^{Earth} + v_{Albedo}]$

↓

Difference spectra:

$$D(E) = [v_{in}^{sky} - v_{in}^{Earth}] + [v_{CXB} - v_{Albedo}]$$

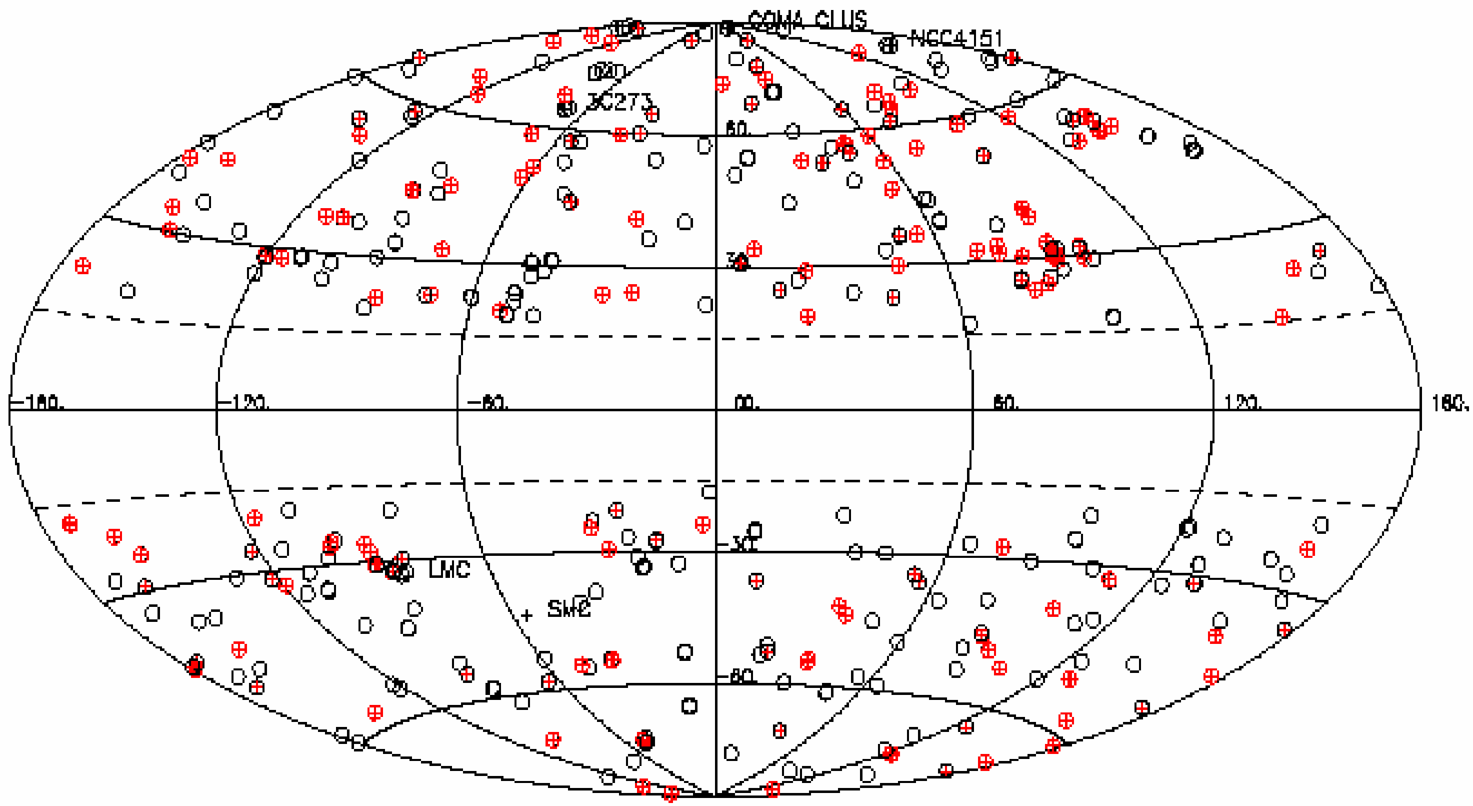
If $v_{in}^{sky} = v_{in}^{Earth}$

↓

$$D(E) = v_{CXB} - v_{Albedo}$$

We have measured both CXB and Albedo spectra.

Blank field selection



✷ Only observations above +15° and below -15° from the galactic plane;

✷ON-source or ±OFF-source excesses below 1σ.

Precautions taken for making $IntrinsicBKG_{Sky}$ = $IntrinsicBKG_{Earth}$

* Only OPs with long duration (> 10 ks), during which v_B^{sky} and v_B^{earth} spectra are measured at almost equal cutoff rigidities.

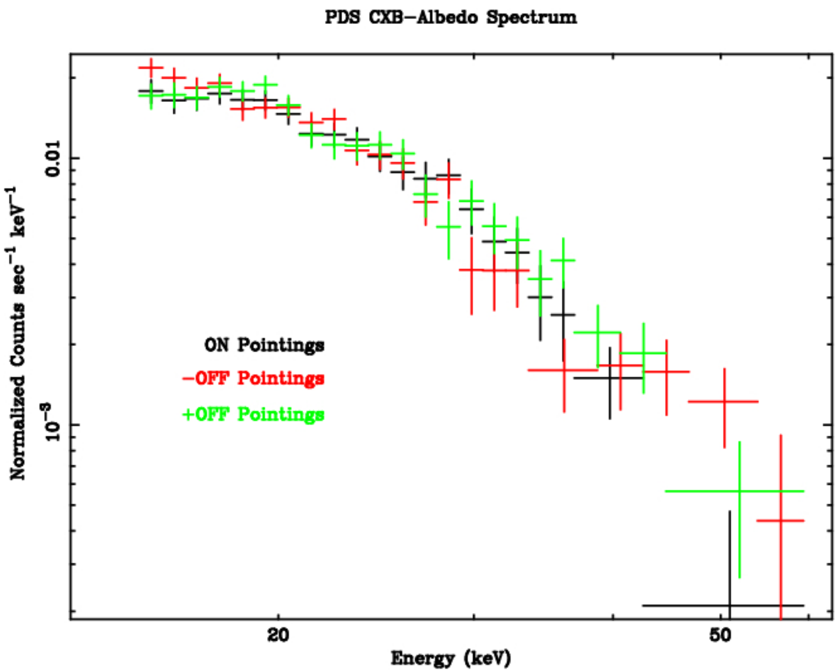
* Separate D(E) determinations for each of the collimator positions (ON, +OFF, -OFF);

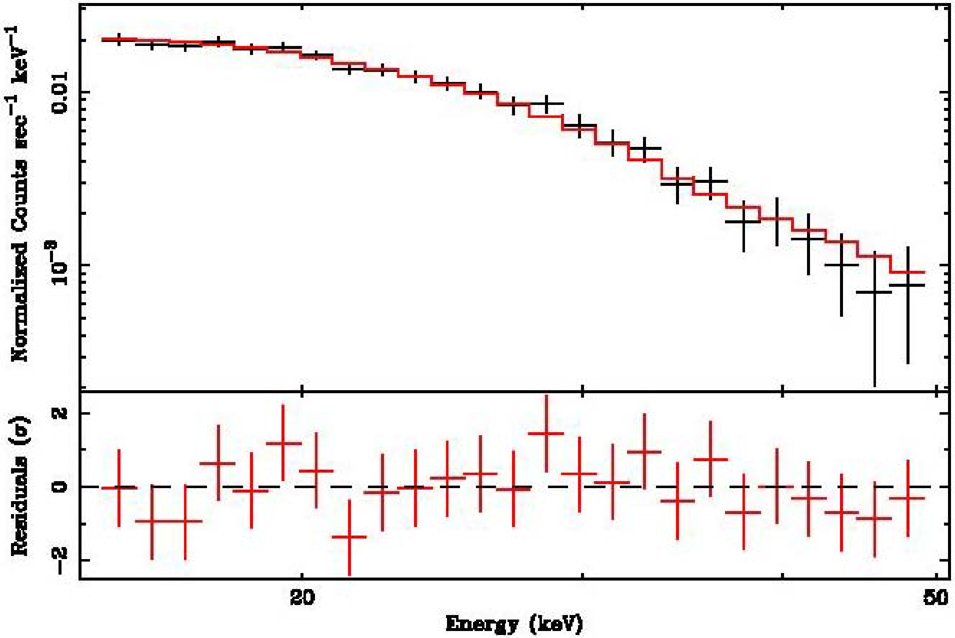
* Only spectra extracted during "dark" Earth pointings;

* For the Earth pointings, only those with the PDS axis well below the Earth limb.

- Total sky exposure time: 4.03 Ms.
- Total earth exposure time = 2.056 Ms

D(E) well determined in 15-50 keV

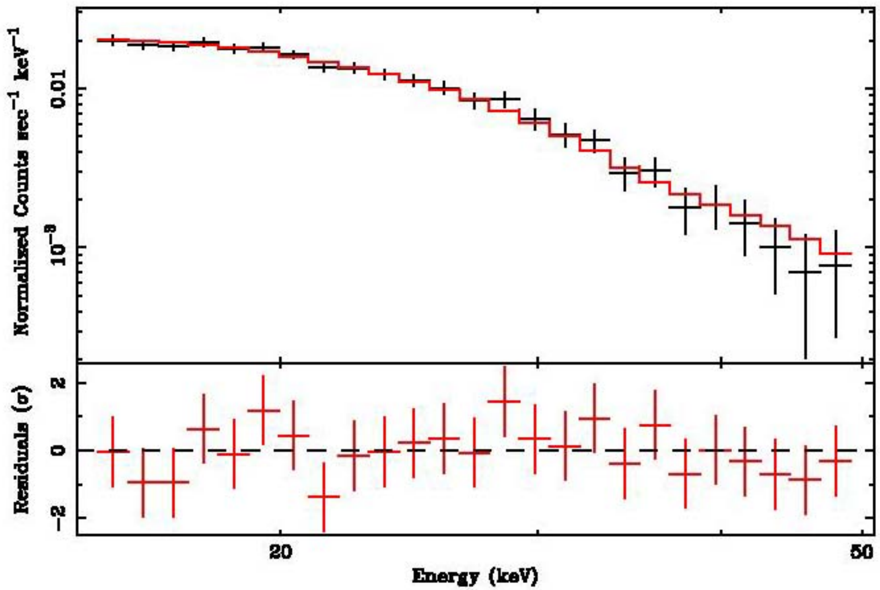




Albedo fit model adopted (on the basis of past results):

$$I(E) = N \exp(-\mu_{air}\, t)\, (E/20)^{-\Gamma_A} \text{ ph cm}^{-2}\text{ s}^{-1}\text{ sr}^{-1}\text{ keV}^{-1}$$

CXB fit models adopted:



1) Power law (PL);
2) Cutoff power law (CUTOFF-PL), i.e., the model adopted by Grub[e]
   et al. 1999:

For Albedo and CXB models, parameter range values were left free to vary in a range consistent with past results, but the normalization (no limitation in the possible values).

Resolved CXB taken into account

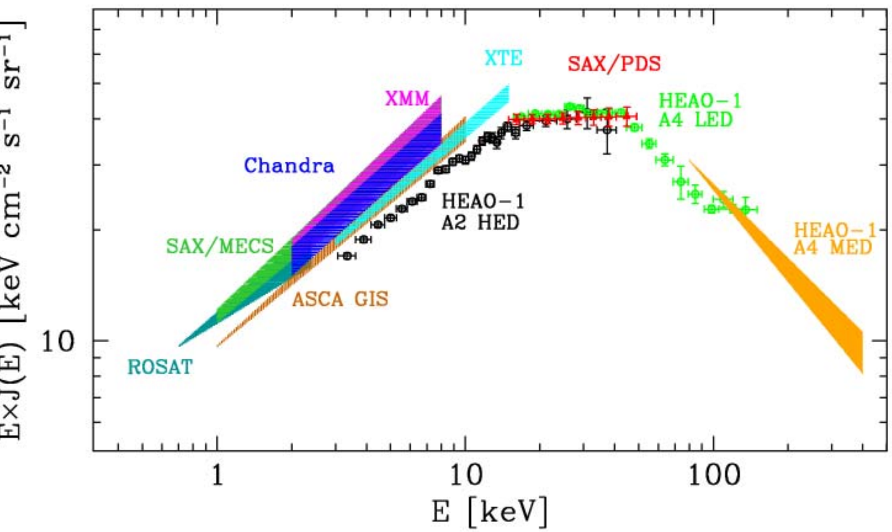
- In 33 of the PDS OFF-source fields, serendipitous sources were detected:
  - 15—50 keV fluxes from 0.1 to 1.5 mCrab
  - PL spectra with $\langle\Gamma\rangle = 1.65 \pm 0.20$.

- The total contribution of resolved sources increases the unresolved CXB intensity by 4.7%.

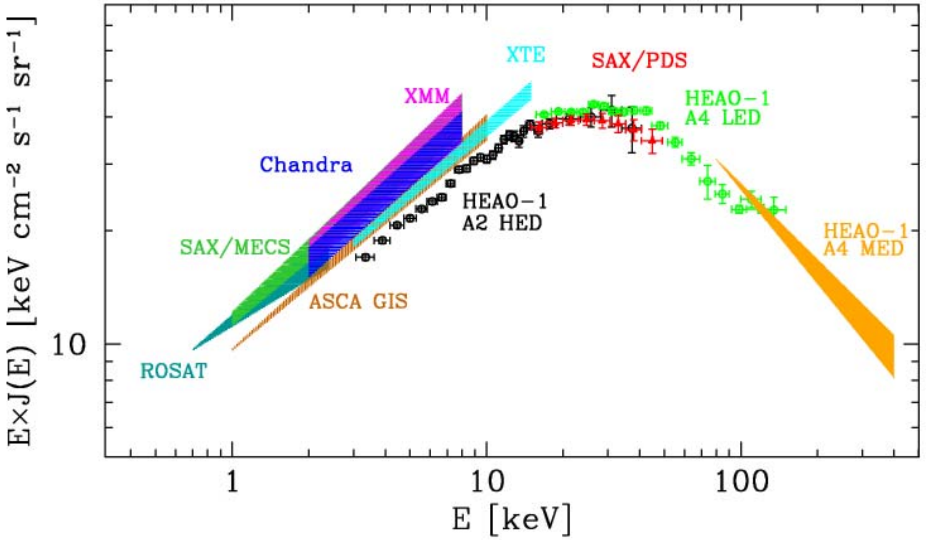
Results

Total CXB spectrum

Fit with a PL

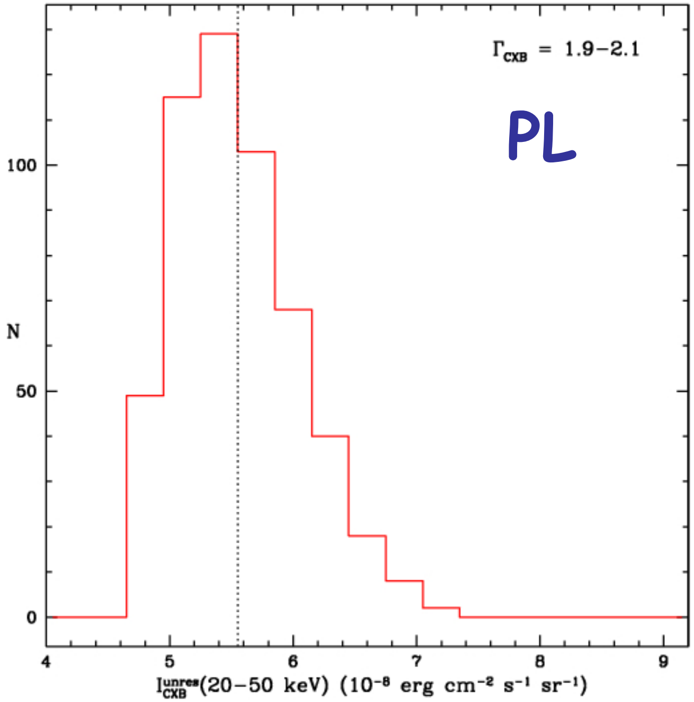


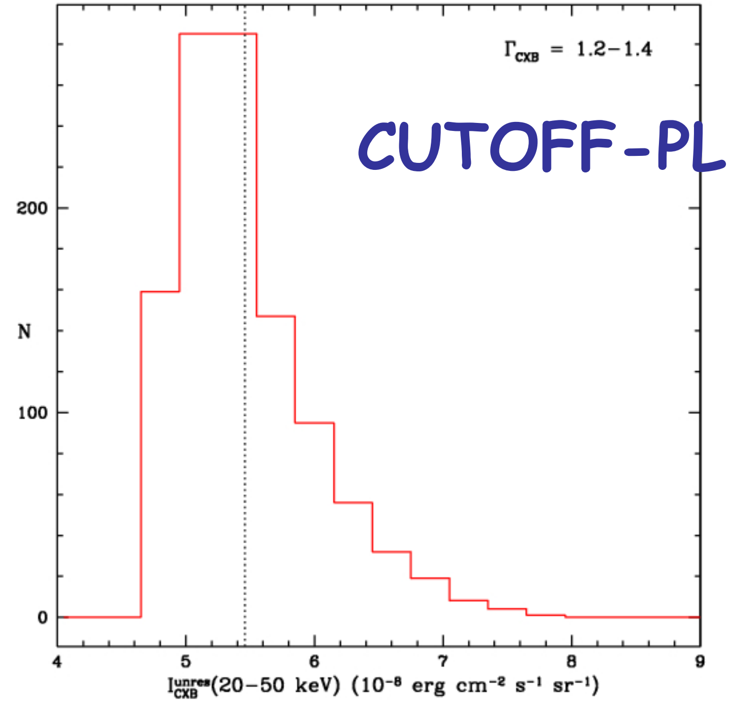
Fit with Cutoff-PL



➢ Best fit fully consistent with HEAO-1 (Marshall et al. 1980, Gruber et al 1999);

Spectral analysis results in the entire multi-parameter space





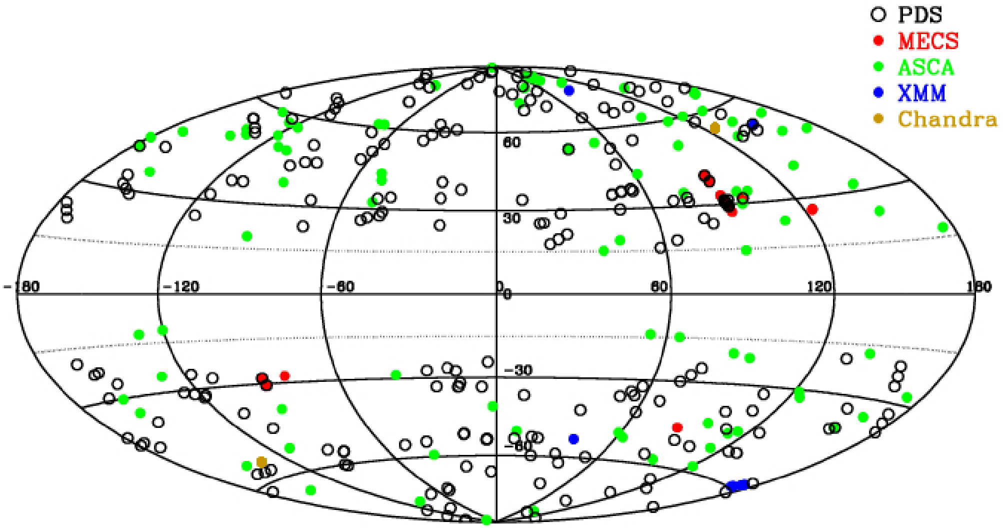
From the frequency distribution of the total 20-50 keV CXB integrated intensity, at 90% confidence level:

$$I_{CXB}^{tot}(20-50keV) < 6.8\times 10^{-8}\ erg/cm^2 s\ sr$$

(12% higher than the value quoted by Gruber et al. 1999)

Observational Consequences

- Even our upper limit disagrees with low measurements (CXO, XMM, BSAX-MECS).
- Differences in calibration cannot explain the discrepances;
- The different sky surveyed? Possible, but not very likely.
- Systematic errors in the response function of the low energy telescopes appear more likely.



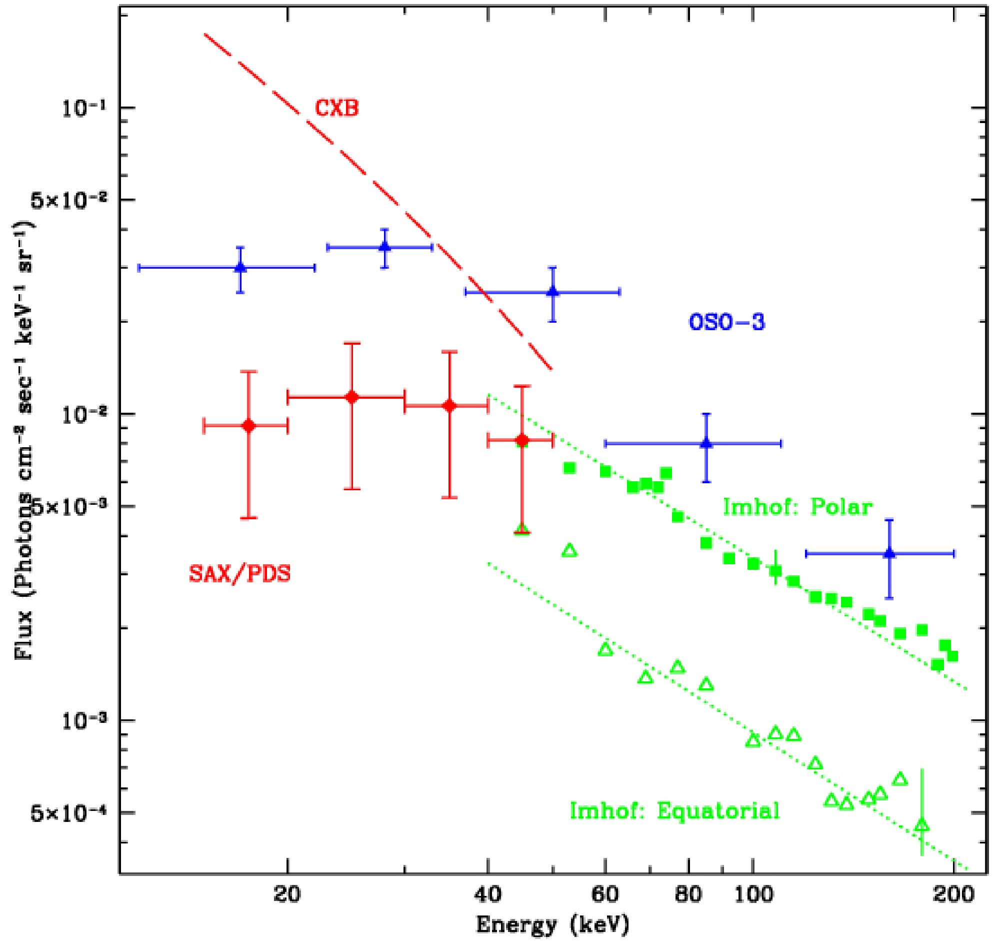
Astrophysical Consequences

- Obtained a robust estimate of the accretion-driven power integrated over cosmic time, including that produced by the most obscured AGNs;
- Total SBH density of $\sim 3\times10^5$ solar masses/Mpc^3;
- Using the "concordance" cosmology model (baryon density of 4×10^{-31} g/cm^3), fraction of all baryons locked in the SBH : 6×10^{-5} ;
- Fraction of heavily obscured AGNs expected: 10% (strong), 20-30% (with focusing telescopes, Simbol X)
- Almost all the 3-8 keV CXB has already been resolved into discrete sources by Chandra;
- Any substantial contribution to CXB from other classes of sources and diffuse WHIM is confined below 3 keV.

Albedo spectrum during dark Earth

- The albedo intensity depends on CR flux at Earth and thus on magnetic latitude.

- The derived spectrum is latitude averaged like the other shown spectra.



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