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The cosmic X-ray background level at its emission peak

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Summary. — We discuss an accurate measurement of the CXB in the 15–50 keV range performed with the *Phoswich Detection System* (PDS) instrument aboard the *BeppoSAX* satellite, whose results have already been recently reported elsewhere (Frontera F. *et al.*, *Astrophys. J.*, **666** (2007) 86). Unlike the recently reported 2–10 keV CXB measurements obtained with the imaging instruments aboard the X-ray satellites *BeppoSAX*, *XMM-Newton*, and *Chandra* that give CXB intensities systematically higher than those obtained with HEAO-1, using the *BeppoSAX* PDS pointings at high galactic latitude ($|b| > 15°$) we measure a CXB spectrum and intensity level in the 15–50 keV energy band, which are consistent with those obtained with HEAO-1. Astrophysical consequences are discussed.

PACS 95.85.Nv – X-ray.
PACS 98.54.Cm – Active and peculiar galaxies and related systems (including BL Lacertae objects, blazars, Seyfert galaxies, Markarian galaxies, and active galactic nuclei).
PACS 98.62.Js – Galactic nuclei (including black holes), circumnuclear matter, and bulges.
PACS 98.70.Vc – Background radiations.
PACS 98.80.Es – Observational cosmology (including Hubble constant, distance scale, cosmological constant, early Universe, etc.).

1. – Introduction

It is well recognized that the Cosmic X-ray Background (CXB) is contributed mainly by Active Galactic Nuclei (AGN) powered by accreting supermassive black holes at the center of large galaxies [1-3]. However, the census of these galaxies is still not completely determined. Optically bright quasars and Seyfert galaxies, most of which covered by amounts of gas $\leq 10^{24}\,\mathrm{cm}^{-2}$ (Compton thin regime) are found to resolve the CXB up to 5–6 keV [4]. Instead at higher energies the resolved CXB is a negligible fraction (a few percent) of the total. This is due to the fact that the contributing sources, on the basis of synthesis models, are expected to be heavily obscured Compton thick AGNs still not singled out (see, *e.g.*, [5]).

However also the CXB intensity level is still a matter of debate. After the first pioneer CXB measurements [6], the major effort to get a reliable estimate of the spectrum in a broad energy band (2–400 keV) was performed in the late 1970's with the A2 and A4 instruments aboard the first *High Energy Astronomical Observatory* (HEAO-1), whose final results obtained with were reported by [7], hereafter G99. According to these authors the CXB energy spectrum $J(E)$ in the 3–60 keV interval is well represented by a power law (PL) with a high-energy exponential cut-off (CUTOFFPL), while the corresponding $E\,J(E)$ spectrum shows a characteristic bell shape with a maximum intensity of 42.6 keV (cm^2 s sr)$^{-1}$ at 29.3 keV.

After HEAO-1 there have been many other CXB measurements at low energies ($<$ 15 keV) with both imaging and non-imaging telescopes aboard satellite missions. These measurements show a low spread of the PL photon index Γ and a high spread (up to $\sim 40\%$) of the CXB intensity, with the lowest CXB estimates obtained with HEAO-1 A2 (see [8], hereafter M80), and the highest with the focusing telescopes aboard *BeppoSAX* [9], *XMM-Newton* [10, 11] and *Chandra* [12] (see details in [13]).

In order to test the validity of these recent results, that should impact also the CXB level at its peak energy (close to 30 keV), we performed an accurate measurement of the total (resolved plus unresolved) high-energy ($>$ 15 keV) CXB intensity by exploiting the pointed observations performed with the *Phoswich Detection System* (PDS) aboard the *BeppoSAX* satellite [14]. A detailed description of the results has already been published [13]. Here we give a summary of our measurement, and discuss their main implications.

2. – The measurement

The measurement of the unresolved $\nu_{\rm CXB}$ count rate is based on the *Sky-Earth Pointing* method, in which we subtract from the background level $\nu_B^{\rm sky}$ measured from a blank sky field ($\nu_B^{\rm sky} = \nu_{\rm CXB} + \nu_{\rm in}^{\rm sky}$) the count rate level measured when the telescope is pointing to the dark Earth ($\nu_B^{\rm Earth} = \nu_A + \nu_{\rm in}^{\rm Earth}$), where ν_A is the count rate due to the X-ray terrestrial albedo entering through the telescope FOV, and $\nu_{\rm in}^{\rm sky}$, $\nu_{\rm in}^{\rm Earth}$ are the instrumental backgrounds when pointing to the sky and to the Earth, respectively. The difference spectrum $D(E) = (\nu_{\rm CXB} - \nu_A) + (\nu_{\rm in}^{\rm sky} - \nu_{\rm in}^{\rm Earth})$ becomes $D(E) = \nu_{\rm CXB} - \nu_A$ if $\nu_{\rm in}^{\rm Earth} = \nu_{\rm in}^{\rm sky}$.

Sky and Earth were observed with the PDS rocking collimators in two different positions: on-axis position, when the collimator axis was parallel to that of the other Narrow Field Instruments aboard BeppoSAX (*ON-source*), off-axis position, when the collimator axis was offset by $\pm 3.5°$ in order to measure the background level (*OFF-source*).

In order to make sure that $\nu_{\rm in}^{\rm Earth} = \nu_{\rm in}^{\rm sky}$ we performed a careful selection of the available data, as described in [13]. In order to satisfy the blank sky field condition, we discarded all pointings within 15° from the galactic plane, while for the OFF-source pointings we filtered out those observations for which the +OFF and −OFF fields could be contaminated, *e.g.*, from serendipitous X-ray sources, fast transients or solar flares. For the ON-source pointings we accepted only those fields for which the difference between the ON-source count rate and count rate measured at either +OFF and −OFF is consistent with zero within 1σ. For other details see [13]. As a result of the above selections, from the entire set of 868 *BeppoSAX* observation periods (OPs) off the galactic plane, the number of useful OPs becomes 275 (127 ON-source, 71 +OFF-source, and 77 −OFF-source) with a total exposure time of 4031 ks. The dark Earth was observed for a total of 2056 ks.

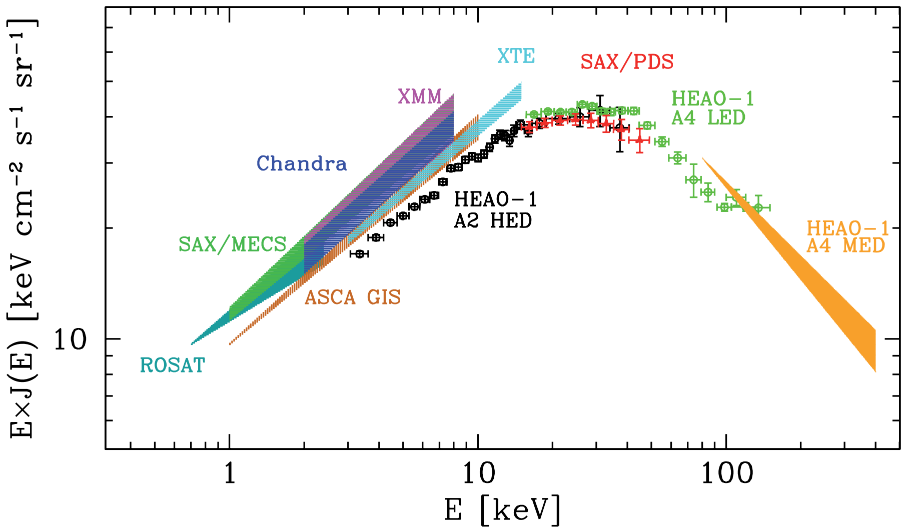

Fig. 1. – Total (unresolved plus resolved) CXB $EF(E)$ spectrum as observed with the PDS experiment (red points) compared with the measurement results obtained with other missions. The CXB spectral shape assumed in the fit is a CUTOFFPL model. Reprinted from [13].

2·1. *Results*. – For the derivation of the CXB intensity the sum $D(E) = D_{\rm ON}(E) + D_{\rm +OFF}(E) + D_{\rm -OFF}(E)$ was used, where $D_{\rm ON}(E)$, $D_{\rm +OFF}(E)$, and $D_{\rm -OFF}(E)$ are the difference spectra for the ON-source, +OFF-source and −OFF-source pointings, respectively. $D_{\rm ON}(E)$, $D_{\rm -OFF}(E)$ and $D_{\rm +OFF}(E)$ were found all consistent with each other within their uncertainties. Thus the sum $D(E)$ was used and determined up to 50 keV.

$D(E)$ was fit with the difference of two model spectra, one to describe the unresolved CXB spectrum and the other to describe the albedo radiation spectrum. The albedo model spectrum was described with a photo-electrically absorbed power law (details in [13]), while the CXB spectrum was assumed to have the CXB spectral shape used by G99 for the HEAO-1 A2 + A4 CXB data, *i.e.* a CUTOFFPL. However a PL, in the 15–50 keV interval, was found to still give a good description of our data.

The resulting fits of the unresolved CXB are described in detail in [13]. The total CXB (unresolved plus resolved) was obtained by adding to the unresolved CXB the contribution of extragalactic sources (mainly AGNs), on the basis of the serendipitous sources that were detected with the PDS. In fig. 1 we show the best fit of our $EF(E)$ CXB spectrum compared with those obtained with other measurements, assuming the spectral shape assumed by G99.

Also the upper limit to the CXB intensity that can be marginally accommodated by our data was investigated by exploring the space of all the parameters involved in the fits (details in [13]). Independently of the CXB model spectrum, in 90% of this multi-parameter space the $I^{\rm tot}_{\rm CXB}(20\text{–}50\,{\rm keV})$ was found to be lower than $6.8 \times 10^{-8}\,{\rm erg\,cm^{-2}\,s^{-1}\,sr^{-1}}$.

3. – Discussion

Comparing our results with the previous ones, the best-fit $I_{\rm CXB}^{\rm tot}(20\text{–}50\,{\rm keV})$ found with the *BeppoSAX* data is in agreement with that obtained with HEAO-1 A2 (M80), and slightly lower (from 3 to 10%, depending on the input model) than that quoted by G99. In addition our upper limit is 12% higher than the best-fit CXB intensity value quoted by G99 and 21% higher than that quoted by M80.

This upper limit still disagrees with the extrapolation to higher energies of the low-energy ($< 10\,{\rm keV}$) CXB estimates obtained with the focusing telescopes aboard *BeppoSAX* [9], *XMM-Newton* [10, 11], and *Chandra* [12]. Thus, if the CXB spectral shape derived with HEAO-1 is correct as assumed, in [13] we discuss the possible instrumental origin of the highest CXB intensities quoted at lower energies. However, given that the summed contribution of the already resolved *Chandra* sources in the 1–8 keV band [12] almost exceed the HEAO-1 level, other interpretations cannot be excluded as discussed in [5], *e.g.*, a sizable population of extremely hard sources appearing only above 5–6 keV. Thus it appears urgent to continue deep X-ray surveys either with operating X-ray telescopes aboard *XMM-Newton*, *Chandra* and *Suzaku* and with future missions like *Simbol X* [15] and *NuSTAR* [16].

Independently of the AGN census, our observational findings bear at least an important astrophysical consequence. They provide a robust estimate of the accretion-driven power integrated over cosmic time, including that produced by the most obscured AGNs. We infer an estimate of the present black-hole mass density of $\sim 3 \times 10^5\ M_\odot\ {\rm Mpc}^{-3}$, using an admittedly uncertain bolometric correction of 30 for the 15–50 keV band and an efficiency of 0.1 in converting gravitational into radiation energy.

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