The autocorrelation function of the soft X-ray background

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Abstract. The first positive detection of the X-ray background fluctuations at small angular scales is reported. ROSAT PSPC archive pointed observations are used to measure fluctuations at scales of $0'.03 - 0'.4$. The pointings have been selected from an area free from galactic contamination. At separations below $\sim 0'.1$ clusters of galaxies become a substantial source of the background fluctuations. The autocorrelation function of the fluctuations in the power law approximation has a slope of $\sim 1$ for all the data but is substantially flatter (with slope of $\sim 0.7$) when pointings containing bright clusters are removed. At separations $0'.3 - 0'.4$ where the ACF estimates based on the ROSAT pointings and All-Sky Survey are available, both data sets give consistent results.

1. Introduction

Fluctuations of the X-ray background (XRB) provide a unique method to investigate statistical properties of the distribution of X-ray sources. At angular scales above $\sim 0'.3$ the ROSAT All-Sky Survey (RASS) revealed distinct variations of the soft XRB (Soltan et al. 1996). Subsequent analysis (Soltan et al. 1999) showed that clustering of active galactic nuclei (which are the main contributor to the XRB) potentially could explain the large amplitude of the XRB autocorrelation function (ACF). However, the amplitude of X-ray source spatial clustering required to reproduce the observed ACF is higher than that derived from direct investigation of the distribution of sources (e.g. Carrera et al. 1998). Thus, it is likely that fluctuations of the soft XRB are produced also by some other effects. In particular, hydrodynamical computations by Cen & Ostriker (1999) show that the process of accumulation of primordial gas in the potential wells created by galaxies and clusters of galaxies produced large scale concentrations of hot plasma. This material is expected to emit thermal bremsstrahlung in the soft X-ray domain. A clumpy distribution of emitting plasma would contribute substantially to the total fluctuations of the XRB. To investigate the importance of different mechanisms producing the XRB anisotropy one needs to measure the amplitude of the XRB fluctuations over a wide range of angular separations and at different energies. In the present work we have determined the autocorrelation function of the soft XRB using a large number of ROSAT.
2. Analysis of the observational data

Visual inspection of the RASS X-ray maps (SNowden et al. 1997) shows that at low energies only selected sky regions seem to be free from thermal emission by hot galactic plasma and not affected by absorption by cold gas. To investigate fluctuations of the extragalactic component of the XRB Soltan et al. (1996) used a section of the RASS maps of approximately 1 sr at the northern galactic hemisphere ($b > 40^\circ, 70^\circ < l < 250^\circ$) apparently least contaminated by local effects. In the present analysis we have concentrated on the same region of the sky. All ROSAT pointed observations within this area with exposure time longer than 5000 s excluding pointings at known extended sources (supernova remnants, nearby normal galaxies, clusters of galaxies) have been used. Total number of pointings satisfying these selection criteria is equal to 141. The data in the gain-corrected pulse height channels 91−131 ('R6 band' in Snowden at al. 1994) with the energy centered at 1.15 keV has been selected. Counts in each field were binned into $8'' \times 8''$ pixels. For each observation the central region containing the target source was eliminated from the data, the size of the removed area was carefully determined. The distribution of counts within the field of view produced by the target source was calculated using the ROSAT telescope point spread function and the radius of the circle to be removed was obtained in such a way that the residual contribution of the target source did not exceed 5% of the local background within the remaining section of the field of view.

To minimize vignetting effects we have used the central section of the PSPC field of view with radius of 13.5'. Contamination by particle background and by soft solar photons scattered in the Earth’s atmosphere was subject to scrutiny for each observation separately. In the vast majority of observations the number of non-cosmic counts was insignificant, and in few cases the observed count rates have been corrected for both these effects.

It is of fundamental importance for the fluctuation analysis to construct a sample of observations for which all the instrumental and non-cosmic effects are constant and do not vary from one observation to another. To check for the possible systematic variations of the telescope/detector system characteristics we have plotted in Fig. 1a and b respectively, the average count rate per pixel as a function of exposure time and date of observation. While the count rates averaged over each field do not show any dependence on exposure time, they vary systematically with the date of the observation. Most probably this effect results from small inaccuracies in the gain corrections. To remove this weak trend, a straight line was fitted to the data and the average count rate in each field was corrected for the slope of the fit.

We denote the intensity of the XRB in the direction defined by the unit vector $\mathbf{n}$ in the $i$-th pointing (= count rate in the corresponding pixel) as $\rho_i(\mathbf{n})$. 
The autocorrelation function of the XRB

Figure 1. Distribution of count rates in the sample vs. exposure time (a), and vs. observation date (b).

The ACF $w(\theta)$ was calculated using the formula:

$$w(\theta) = N \frac{\sum_i (\rho_i(n)\rho_i(n'))}{\left[\sum_i \langle \rho_i \rangle\right]^2} - 1,$$

where the sum extends over all pointings ($N = 141$), the directions $n$ and $n'$ are separated by the angle $\theta$, and $\langle \rho_i \rangle$ denotes the count rate in the $i$-th field calculated averaged over pixels used in the calculations for given $\theta$.

3. Autocorrelation function from pointings and RASS

The ACF based on the pointings is shown in Fig. 2a. The strong signal at separations below $\sim 100''$ results from “granular” nature of the XRB. The shape of the ACF at these separations is defined by the PSF of the telescope/detector system averaged over the field of view and photon energies. Variations of the ACF at larger separations also result from the discrete structure of the XRB. Here the major role play pairs (or multiplets) of strong sources in each field; the larger the number of separate pointings used in the calculations, the smaller amplitude of the ACF fluctuations.

Apart from the fluctuations, the ACF amplitude shows a systematic decline with increasing separation. Above $\sim 1000''$ the signal becomes too weak in comparison with the fluctuations produced by the strong sources, that the ACF cannot be estimated reliably.

Present measurements of the ACF are shown together with the RASS estimates (taken from Soltan et al. 1999) in Fig. 2b (note the logarithmic scale). Open circles correspond to the results shown in Fig. 2a averaged in logarithmic bins. Both measurements are in satisfactory agreement taking into account
Figure 2. a) The autocorrelation function of the soft XRB at small separations based on ROSAT pointings (note logarithmic and linear scales of the ordinate axis).
b) Estimates of the ACF based on the RASS and pointings. Dots with the error bars show the RASS data; open circles - all 141 pointings, crosses - only fields without bright clusters (133 pointings)

large uncertainties of both measurements (error bars of the RASS result represent scatter due to statistical fluctuations).

The ACF signal is now measured in the range 0\(^\circ\)03 – 10\(^\circ\). It is likely that various effects contribute the XRB fluctuations at different scales. To assess what role play the bright clusters of galaxies we have repeated all the calculations without fields containing known clusters\(^1\). The ACF calculated for the restricted data set (133 pointings) is shown in Fig. 2b with crosses. It appears that clusters contribute to the XRB fluctuations noticeably only at separations below \(\sim 0\f 1\). The ACF without known clusters becomes substantially flatter than for all the data. Detailed models of the ACF will be discussed in a separate paper.

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\(^1\)Pointings with known clusters as observational targets have been removed from the sample in the preliminary selection of the material; here we consider only serendipitous clusters in the field of view.