The High-energy X-ray Background and Limits on Large Scale Structure

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1. INTRODUCTION

At present there are in use three different models to characterize the large scale structure of the universe. The clustering model (Soneira and Peebles, 1978) assumes that the superclusters are high density islands in a low density sea. The void model (Joeveer and Einasto, 1978), on the other hand, assumes that the voids are isolated low density islands in a high density sea. The sponge model (Gott et al., 1986) assumes that high and low density regions occupy equal volumes, and that the high and low density regions are both connected. The straightforward way to decide among these three models is the direct investigation of the spatial distribution of the galaxies. Nevertheless, there is an essentially different observational method that may also be useful to obtain some information about these models. The X-ray background radiation (XRB) is due either to the bremsstrahlung of hot intergalactic gas, or to the sum of the radiation of unresolved discrete sources (E.G. Boldt 1987). If the "discrete" origin is correct, then obviously the actual number of sources, and hence their total intensity, may vary from one part of the sky to another. Thus, in this case one has the possibility to estimate the number of sources in a given volume from the observed isotropy of the XRB. For example, Hamilton and Helfand (1987) suggest that the number of sources must be larger than $5000/(\text{degree})^2$. Any such estimate needs several assumptions. In the previous works one usually assumed that the sources were distributed completely randomly; see, e.g. Fabian (1972). Nevertheless, if the XRB is generated by young galaxies (Bookbinder et al. 1980), it is not excluded that the sources of the SRB are also grouped similarly to galaxies. Because in this case the distribution of sources of the XRB is not completely random, one may expect a different type of fluctuations in the intensity of the XRB. In addition, since the grouping may be quite different for the three structure models, the expected fluctuations may also be different. There is a chance to discriminate among them using the observed isotropy of XRB. The basic observational datum concerning the isotropy of the XRB is well-known: the fluctuations in the intensity are smaller than 3%, if 3° x 3° pixels are used

J. Audouze et al. (eds.), Large Scale Structures of the Universe, 203–206.

https://doi.org/10.1017/S0074180900136034 Published online by Cambridge University Press

Shafer (1983).

II. EXPECTED FLUCTUATIONS

A primitive description of the island model is as follows: in the part of the universe where the XRB is emitted a volume V_o is given. In V_o there are K spheres with radii R_i; i = 1, 2, ..., K. The sources of the XRB are inside of these spheres with a constant density N. The total number of sources N is given by

$$N = \sum_{i=1}^{K} \frac{4\pi}{3} N R_i^3 = \sum_{i=1}^{K} N_{si}. \qquad (1)$$

If any source has the same constant emissivity J, then the total intensity expected from V_o is given by

$$I = J \frac{4\pi}{3} N \sum_{i=1}^{K} \frac{R_i^3}{d_i^2}, \quad d_i >> \sqrt[3]{\frac{V_o}{K}} = \sqrt[3]{\bar{V}} = 10\, H^{-1} L_{10} = L \qquad (2)$$

where d_i is the distance of i-th sphere, L_{10} should be of order of unity if $\bar{V}$ is given in Mpc^3, H is the Hubble parameter in the units of 100 km/(sec.Mpc). Because R_i and d_i are clearly not correlated, we have

$$\frac{\delta I}{I} = \frac{1}{\sqrt{K}} \sqrt{\left(\frac{\delta N_s}{N_s}\right)^2 + \left(\frac{\delta(d^{-2})}{d^{-2}}\right)^2} = \frac{A}{\sqrt{K}}. \qquad (3)$$

Detailed calculations show that A should be of order of unity and can hardly be smaller than 1. The most primitive void model assumes that the spheres are empty, and the gap among the spheres is filled with sources of constant density n. Then we have

$$\sum_{i=1}^{K} \left(n\bar{V} - \frac{4\pi}{3} N R_i^3\right) = \sum_{i=1}^{K} N_{si}, \qquad (4)$$

$$\frac{\delta I}{I} = \frac{1}{\sqrt{K}} \sqrt{\left(\frac{\delta N_s}{N_s}\right)^2 + \left(\frac{\delta(d^{-2})}{d^{-2}}\right)^2} = \frac{B}{\sqrt{K}} \qquad (5)$$

where B is not necessarily identical to A, but it is again of order unity and can hardly be smaller than 1. It is essential to note that the randomness in the spatial distribution of superclusters and voids is a necessary requirement. One has to consider the superclusters and voids as isolated objects. On the other hand, in the sponge model one assumes that the neighbourhood voids (superclusters) are connected; in particular (Gott et al. 1986), one may assume that the sources are distributed randomly in 1/2 V_o. Thus here the fluctuation are given again by the well-known relation (Fabian 1972).

$$\frac{\delta I}{I} = \frac{\delta(d^{-2})}{\sqrt{N}\, d^{-2}} = \frac{F}{\sqrt{N}}; \quad F \leq A \text{ or } B. \qquad (6)$$

https://doi.org/10.1017/S0074180900136034 Published online by Cambridge University Press

(The constraint that F is smaller than A or B is obvious from the fact that here only the "distance fluctuations" are present.) Simply, if one assumes the validity of the sponge model, no new fluctuations are expected. In the two remaining models, on the other hand, new fluctuations arise for

$$\bar{N}_S = \frac{1}{K} \sum_{i-1}^{K} N_{si} >> 1. \qquad (7)$$

III. FRIEDMANN MODELS

If J is constant during the evolution of universe then for the Friedmannian universes one obtains

$$K = \frac{\omega}{V} \int_{\chi_1}^{\chi_2} R^3(\chi)\ g^2(\chi)\ d\chi,\ 0 < \chi_1 < \chi_2 < \infty,\ \chi = \chi_o - \eta, \qquad (8)$$

where $g(\chi) = \sin \chi$ or χ or $\mathrm{sh}\ \chi$, and χ is the comoving coordinate; χ_o is the distance of the horizon; ω is the solid angle determining the observed part of sky; $\chi_1(\chi_2)$ is the minimal (maximal) distance where the XRB is emitted; $R(\chi)$ is the radius of the universe. For the flat case $g(\chi) = \chi$

$$K = \frac{\omega}{\bar{V}} \left(\frac{2c}{H}\right)^3 \int_{\chi_1}^{\chi_2} (1-\chi)^6 \chi^2 d\chi, \qquad (9)$$

where c is the velocity of light, and H = 100 h km/(sec.Mpc) is the Hubble-parameter. In order to calculate the distance fluctuations in eq (5), d must be replaced by d_χ, the "luminosity distance". The result is

$$\left(\frac{\delta I}{I}\right)_{dist} = \frac{C}{\sqrt{K}} = \left[\left(\frac{I_1(\chi)\ I_2(\chi)}{I_3(\chi)} - 1\right)^{1/2}\right]_{\chi_1}^{\chi_2} \qquad (10)$$

where $Ii(\chi)$ are functions of χ and χ_1, χ_2 correspond to the lower and upper redshifts z_1; z_2. Using a solid angle $\omega = (3° \times 3°)\ \Theta_3$ and an average structure volume $\bar{V} = L^3 = (10\ \mathrm{Mpc})^3\ L_{10}^3$, we have the scaling $\delta I/I \propto L_{10}^{3/2}\ \Theta_3^{-1}$. The distance fluctuations of eq (10) give a lower limit to the total fluctuations (since additional fluctuations would come from number effects, luminosity differences, etc). Thus

$$\left(\frac{\delta I}{I}\right)_{dist} = \frac{C}{\sqrt{K}} < \left(\frac{\delta I}{\delta}\right)_{tot} \qquad (11)$$

The values of $(\delta I/I)_{dist}$ are, for $L_{10} = \theta_3 = 1$:

z_1	z_2	flat	$\Omega_o = 0.5$	$\Omega_o = 0.1$
0.5	1	$1.6\ 10^{-2}$	$1.5\ 10^{-2}$	$1.3\ 10^{-2}$
	4	$2.3\ 10^{-2}$	$2.1\ 10^{-2}$	$1.9\ 10^{-2}$

Since $L_{10} \gtrsim 3$ (de Lapparent et al 1986), and $\delta I/I$ scales as $L_{10}^{3/2}$, we see that

$$\left(\frac{\delta I}{I}\right)_{tot} \gtrsim 6\text{-}7\%. \qquad (12)$$

This result is valid for structures of constant physical size, $L = L_o$ = constant. For the case when it is the comoving size which remains constant, see also Mészáros and Mészáros (1987). This is valid for both island and void models, but not to sponge models (since there are no structures with a characteristic $\overline{V} = L^3$). It applies also in the case where the sources of the background are clouds of gas, emitting bremsstrahlung, rather than galaxy-type objects, if these are clustered in the same way as the latter.

IV. DISCUSSION

The spatial fluctuations of eq (12) exceed the observed value of 3% by at least a factor 2. The lower limit of $z_1 = 0.5$ excludes from this calculation most of the optically identified x-ray point sources. In fact Shafer (1983) finds that known x-ray emitting AGN's may be already sufficient to explain the HEAO-1 3% fluctuations. The fluctuations of eq (12) would therefore come on top of that, and make the limit even more stringent. From this one may conclude either that a) the large scale structure at $z > 0.5$ is significantly less clustered than at $z < 0.5$, e.g. as in the sponge model, or b) the x-ray sources at $z > 0.5$ do not trace the matter structures. If the x-ray background has a significant contribution from young AGN's protogalaxies, or gas clouds, at $z < 0.5$, these cannot be very clustered.

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Acknowledgements: This research has been partially supported through NSF AST 8514735.

https://doi.org/10.1017/S0074180900136034 Published online by Cambridge University Press