1983A&A...118..154N

Astron. Astrophys. 118, 154–156 (1983)

ASTRONOMY
AND
ASTROPHYSICS

The contribution of quasi-stellar objects to the cosmic X-ray background

J. V. Narlikar[1] and G. Burbidge[2]

[1] Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400005, India
[2] Kitt Peak National Observatory*, 950 North Cherry Avenue, Tucson, AZ 85726, USA

Received May 5, accepted October 20, 1982

Summary. The contribution of QSOs to the X-ray background over the energy range 1–3 keV is estimated in two different ways. It is shown that QSOs can only contribute a fraction to the entire observed background flux even if they are considered to be local objects.

Key words: cosmic background radiation – X-rays: quasars QSOs

I. Introduction

The discovery that QSOs are powerful emitters of X-rays has led to several investigations of the extent to which they are responsible for generating the observed X-ray background flux. The early estimate by Setti and Woltjer (1979) based on only four bright X-ray QSOs led them to the conclusion that unless the QSO number count flattened sufficiently fast at faint magnitudes ($m_B \gtrsim 20$) the QSOs would produce a background X-ray flux much larger than that observed. The first X-ray studies of QSOs using the *Einstein* observatory (Giacconi et al., 1979; Tananbaum et al., 1979) also led to similar conclusions. All of these investigators concluded that the above problem is made worse if it is assumed that quasars are considerably nearer than their Hubble distances, so that this argument was used against the local hypothesis of QSOs.

Subsequently more detailed studies of X-ray QSOs have led to downward revisions of the QSO contributions to the X-ray background, within the framework of the cosmological hypothesis. For example, Zamorani et al. (1981) estimate that QSOs brighter than $m_B = 20$ probably account for 30% of the observed X-ray background and they argue that since a flattening of number counts of QSOs fainter than $m_B = 20$ is observed, the background catastrophe might be resolved. Kembhavi and Fabian (1982) similarly estimate that the X-ray QSOs may contribute no more than 45% to the X-ray background.

It is evident that the earlier estimates were high because (i) the X-ray luminosity of a typical QSO was overestimated and (ii) the number counts were assumed to be too steep. For example, optical number counts certainly show a flattening beyond 20^{m}, while the recent counts of extragalactic X-ray sources show that their $\log N - \log S$ curve is consistent with a uniform distribution in a Euclidean universe (cf. Maccacaro et al., 1982; Piccinotti et al., 1982). Even the present estimates may not be reliable in view of the caution voiced by Margon et al. (1982) who argue that the various uncertainties surrounding the luminosity and number density of X-ray QSOs make their background contribution highly uncertain and perhaps quite small.

In this paper we present two methods of estimating the X-ray background which rely less on the as yet uncertain theoretical models of luminosity or density evolution etc., and more on observational estimates. Our calculations will show that even if the QSOs are local, their net contribution to the X-ray background is less than half.

In the local hypothesis most of the QSOs seen are assumed to be at distances not beyond 30–100 Mpc. Earlier Rowan-Robinson (1973) estimated the contribution of radio QSOs to radio background and concluded that this assumption is not inconsistent with the radio data. So far as the optical night sky background is concerned, it is believed to arise mostly from galaxies rather than from QSOs. We will use this fact in the first of our two methods.

II. Estimate based on the optical night sky background due to galaxies

Let B_0 and B_x denote the observed optical and X-ray backgrounds over specified frequency ranges. Let β denote the ratio of the space density of QSOs to the space density of galaxies. Similarly let σ denote the ratio of mean optical QSO luminosity to mean galaxy luminosity. Then by a simple scaling argument it follows that galaxies and QSOs contribute, respectively, $(\beta\sigma+1)^{-1}$ and $\beta\sigma(\beta\sigma+1)^{-1}$ of the optical background, provided their evolution with redshift z (if any) is the same.

Next suppose that k is the ratio of the mean X-ray luminosity of QSOs (over the specified frequency range) to their mean optical luminosity still assuming the same evolution. Then the QSOs produce an X-ray background of $k\beta\sigma(\beta\sigma+1)^{-1}$. Our purpose is to determine the fraction

$$f = \frac{k\beta\sigma B_0}{(\beta\sigma+1)B_x}. \tag{1}$$

In what follows we will assume that $\beta\sigma \ll 1$. If it should turn out that $\beta\sigma$ is comparable to or exceeds 1, our upper bound on f in (11) becomes even lower.

To estimate k, β, and σ we proceed as follows. First we determine k. Figure 1 of Zamorani et al. (1981) shows that the regression lines between the X-ray flux S_x, and the optical flux of

Send offprint requests to: G. Burbidge

---

* Operated by the Association of Universities for Research in Astronomy under contract with the National Science Foundation

1983A&A...118..154N

X-ray selected QSOs intersect at $m_B \approx 17^{\mathrm{m}}.2$ and $S_x \cong 9\,10^{-13}$ erg cm^{-2} s^{-1}, over 0.25–3.3 keV. We will consider the X-ray frequency range as the band 1–3 keV. Over this band the above value of S_x becomes $\sim 5\,10^{-13}$ erg cm^{-2} s^{-1}. However, as pointed out by Margon et al. (1982) the luminosities estimated by X-ray selected quasars tend to give an overestimate of S_x. Many of the flux densities S_x given in Fig. 1 of Zamorani et al. (1981) are quoted as upper limits. We therefore consider that $S_x \sim 10^{-13}$ erg cm^{-2} s^{-1} over the 1–3 keV range may be a fair estimate of the X-ray flux density corresponding to $m_B = 17.2$. Converting the latter to a bolometric optical flux density $S_0 \sim 3\,10^{-12}$ erg cm^{-2} s^{-1}, we get

$$k = \frac{S_x}{S_0} \sim \frac{1}{30}. \tag{2}$$

It is worth pointing out how the above estimate is related to the nominal power-law energy slope between the optical and X-ray bands. This slope, usually denoted by α_{0x}, equals 1.80 corresponding to $k = 1/30$. The rather high value of α_{0x} chosen here reflects our view that the "typical QSO", which is radio quiet and of high redshift ($z > 1$) is not a powerful X-ray source. This was one of the two alternatives suggested by Margon et al. (1982) from their study of serendipitous X-ray QSOs. By way of comparison, if $\alpha_{0x} \cong 1.55$, $k \cong 1/6$.

We next consider the number counts of galaxies and QSOs down to the same apparent magnitude. Consider galaxies first. Let L be a typical galaxy luminosity and suppose the specified apparent magnitude corresponds to a distance R_G. If n_G is the number density of galaxies, then the total number down to the flux level

$$l = \frac{L}{4\pi R_G^2} \tag{3}$$

is given by

$$N_G = \frac{4\pi}{3} R_G^3 n_G = \frac{4\pi}{3} n_G \left(\frac{L}{4\pi l}\right)^{3/2}. \tag{4}$$

Here we have used Euclidean geometry for our calculation. We will discuss possible implications of cosmology shortly. A similar calculation for QSOs gives their number as

$$N_Q = \frac{4\pi}{3} (\beta n_G) \left(\frac{L\sigma}{4\pi l}\right)^{3/2}. \tag{5}$$

Therefore we get from (4) and (5)

$$\beta\sigma^{3/2} = \frac{N_Q}{N_G}. \tag{6}$$

We are concerned here with the local hypothesis of QSOs, thus (5) is valid even at low values of l. For galaxies, however, we have to include redshift dependent factors on the right hand sides of (3) and (4). So far galaxy counts at faint magnitudes do not show any marked tendency for evolution, with the result that (4) is changed to

$$N_G = \frac{4\pi}{3} n_G \left(\frac{L}{4\pi l}\right)^{3/2} F(q_0, z), \tag{7}$$

where F depends on the deceleration parameter q_0 of the cosmological model and z denotes the redshift of the most remote galaxy. The function F has the value unity at $z = 0$ and it steadily decreases. Hence (6) is modified to

$$\beta\sigma^{3/2} = \frac{N_Q}{N_G} F. \tag{8}$$

Number counts of galaxies [see for instance the composite curve of Tyson and Jarvis (1979)] suggest $\sim 4\,10^3$ galaxies per square degree down to $22^{\mathrm{m}}.5$. Bahcall and Soneira (1981) place an upper limit of ~ 50 QSOs per square degree down to the same magnitude. Direct measurements of QSO number densities at such faint magnitudes are few, and it is too early to say what is the correct value. We use the estimate of Koo and Kron (1980) of 200 QSOs per square degree at $22^{\mathrm{m}}.5$, although we believe it to be an overestimate. Therefore if we evaluate $\beta\sigma^{3/2}$ from (8) at $22^{\mathrm{m}}.5$ we get

$$\beta\sigma^{3/2} \cong 5\,10^{-3} F. \tag{9}$$

If we assume that galaxies down to this magnitude have the redshift ~ 1, we get $F \sim 0.1$ for $q_0 = 0$. At fainter magnitudes the estimate N_Q/N_G will decrease further since the slope of galaxy counts at $22^{\mathrm{m}}.5$ ($d \log N_G/dm \sim 0.41$) is larger than the slope of quasar counts. Also F will be even less than that estimated above. Therefore

$$\beta\sigma^{3/2} \lesssim 5\,10^{-4} \tag{10}$$

seems to us a fair upper bound.

Returning now to (1) we put $B_0 \simeq 2.5\,10^{-5}$ erg cm^{-2} s^{-1} sterad^{-1} (Lang, 1980) and $B_x \simeq 1.9\,10^{-8}$ erg cm^{-2} s^{-1} sterad^{-1} (Schwartz, 1979) and use (2) and (10) to get

$$f \lesssim 0.022\,\sigma^{-1/2}. \tag{11}$$

To estimate σ we first ask what is the average value of L. The luminosity function derived by Schechter (1976) is expressed analytically in the form ($H_0 = 50$ km s^{-1} Mpc^{-1})

$$\phi(L) = \frac{\phi_0}{L_0}\left(\frac{L}{L_0}\right)^{-5/4} \exp\left(-\frac{L}{L_0}\right), \tag{12}$$

where ϕ_0 and L_0 are constants, with $L_0 \sim 5\,10^{43}$ erg s^{-1}. In the cosmological hypothesis this would give $\sigma \sim 10$. In the local hypothesis, if QSOs are brought 30 times closer, $\sigma^{1/2}$ is reduced by the same factor, i.e., to $\sigma^{1/2} \sim 0.1$. This gives $f \lesssim 22\%$. In this case (10) places an upper bound of 1 QSO for every two galaxies. Even if QSOs are brought 100 times closer, f increases to $\lesssim 60\%$. We therefore conclude that there is no excess background catastrophe for the local hypothesis of QSOs.

III. Direct estimate of contribution from QSOs in our immediate neighborhood

We now consider the same problem from another direction. We shall estimate the upper bound on f by a direct computation of the X-ray background from QSOs in our immediate neighborhood. Let us designate the radius of this spherical region centered on us by R. Euclidean geometry holds within R.

Suppose that the QSOs have an X-ray luminosity function given by

$$\phi(L_x) = \lambda L_x^{-\gamma}, \quad \gamma > 2, \quad L_1 \lesssim L_x \lesssim L_2. \tag{13}$$

Piccinotti et al. (1982) have derived such luminosity functions for active galactic nuclei, with $\gamma \simeq 2.75$. Then the number N_Q of QSOs within distance R is given by

$$N_Q=\frac{4\pi}{3}R^3\int\limits_{L_1}^{L_2}\phi(L_x)dL_x\cong\frac{4\pi}{3}\frac{\lambda}{\gamma-1}R^3L_1^{1-\gamma}, \tag{14}$$

since, in general $L_2 \gg L_1$. The X-ray background produced by these QSOs per steradian is given by

$$B_{XQ}(R)=\int\limits_{L_1}^{L_2}\int\limits_{0}^{R}\Phi(L_x)\frac{L_x}{4\pi r^2}dL_x\cdot r^2dr$$

$$\cong\frac{3}{4\pi}\left(\frac{\gamma-1}{\gamma-2}\right)N_Q\frac{L_1}{4\pi R^2}. \tag{15}$$

Although we have used a specific luminosity function to arrive at (15), any other form of the luminosity function sufficiently steep between L_1 and L_2 will give a similar result, differing from (15) by a multiple of order unity.

To evaluate (15) we now identify our local region as made up of bright QSOs with $m_B \lesssim 18^m$, which corresponds to an optical flux density of $S_0 \sim 1.4\,10^{-12}$ erg cm^{-2} s^{-1}. Using the scale factor $k=1/30$ from (2) gives the corresponding $S_x \sim 4.7\,10^{-14}$ erg cm^{-2} s^{-1} over 1–3 keV. This value of S_x will be an *overestimate* for the factor $(L_1/4\pi R^2)$ appearing in (15) since that factor corresponds to the flux density of the *weakest* of our neighborhood QSOs. At this magnitude limit the counts of Braccesi et al. (1980) give $N_Q \sim 2\,10^4$.

Substituting these values into (15), with $\lambda=2.75$ gives

$$B_{XQ}(R)<5.2\,10^{-10}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,sterad^{-1}}$$

$$\simeq 0.028\,B_x. \tag{16}$$

Thus the bright QSOs contribute only 2.8% of the total X-ray background.

Finally we relate $B_{XQ}(R)$ to the total background B_{XQ} produced by QSOs out to very large redshifts. Ignoring any K-correction and evolutionary corrections we can express our answer in the following form. Suppose R corresponds to a Hubble redshift $z \simeq RH_0/c \ll 1$. Then in general,

$$B_{XQ}(R)=azB_x, \tag{17}$$

where a is a numerical constant which varies between 2 and 3 for the usual range of Friedmann models. For example, $a=2$ for $q_0=0$, $a=4/(3\pi-8)\simeq 2.8$ for $q_0=1$. Taking the lower limit, we get from (16) and (17)

$$B_{XQ}<0.014\,z^{-1}B_x, \quad \text{i.e.,} \quad f<0.014\,z^{-1}. \tag{18}$$

If we assume that $z \cong 0.03$, i.e., all QSOs with $m_B < 18^m$ are at distances $\lesssim 180$ Mpc ($H_0 = 50$ km s^{-1} Mpc^{-1}) we arrive at $f<45\%$. For $q_0=1$ the corresponding limit on F is 30%. Conversely, we may use (18) to put limits on how close the QSOs can be before the X-ray background constraint is violated. These limits could be made more precise when we have more information on the X-ray luminosity function of QSOs.

IV. Conclusion

Present estimates show that X-ray QSOs are not likely to make a large contribution to the X-ray background, even if they are local. These numerical estimates may be revised as more data become available on the X-ray luminosity function and the number density of X-ray quasars.

For example, if our estimates of S_x in Sects. II and III turn out to be too low (e.g. if $k=1/6$) then the QSOs cannot be very local. On the other hand, if the QSO number density at faint magnitudes turns out to be lower than that assumed here, the constraint on the local hypothesis is relaxed further. Our *method* of computation will not lose validity, however, and we believe that future observations will tend to lower the value of f.

Acknowledgements. We thank Drs. Dave De Young and Ajit Kembhari for discussions. J.V.N. gratefully acknowledges the hospitality of Kitt Peak National Observatory.

References

Bahcall, J.N., Soneira, R.M.: 1980, *Astrophys. J. Letters* **238**, L17
Braccesi, A., Zitelli, V., Bonoli, F., Formiggini, L.: 1980, *Astron. Astrophys.* **85**, 80
Giacconi, R., Bechtold, J., Branduardi, G., Forman, W., Henry, J.P., Jones, C., Kellogg, E., Van der Laan, H., Liller, W., Marshall, H., Murray, S.S., Pye, J., Schreier, E., Sargent, W.L.W., Seward, F., Tananbaum, H.: 1979, *Astrophys. J. Letters* **234**, L1
Kembhavi, A.K., Fabian, A.C.: 1982, *Monthly Notices Roy. Astron. Soc.* **198**, 921
Koo, D.C., Kron, R.G.: 1982 (preprint)
Lang, K.R.: 1980, Astrophysical Formulae, Springer, Berlin, Heidelberg, New York, p. 602
Maccacaro, T., Feigelson, E.D., Fener, M., Giacconi, R., Gioia, I.M., Griffiths, R.E., Murray, S.S., Zamorani, G.: 1982, *Astrophys. J.* **253**, 504
Margon, B., Chanan, G.A., Downes, R.A.: 1982, *Astrophys. J. Letters* **253**, L7
Piccinotti, G., Mushotsky, R.F., Boldt, E.A., Holt, S.S., Marshall, F.E., Serlemitsos, P.J., Shafer, R.A.: 1982, *Astrophys. J.* **253**, 485
Rowan-Robinson, M.: 1973, *Astron. Astrophys.* **23**, 331
Schechter, P.: 1976, *Astrophys. J.* **203**, 297
Schwartz, D.A.: 1979, Proc. IAU/COSPAR *Symp.* on X-ray Astronomy, Innsbruck, Austria, eds. W. A. Baity and L. E. Peterson, Pergamon Press, Oxford, p. 453
Setti, G., Woltjer, L.: 1979, *Astron. Astrophys. Letters* **76**, L1
Tananbaum, H., Avni, Y., Branduardi, G., Elvis, M., Fabbiano, G., Feigelson, E., Giacconi, R., Henry, J.P., Pye, J.P., Soltan, A., Zamorani, G.: 1979, *Astrophys. J. Letters* **234**, L9
Tyson, J.A., Jarvis, J.F.: 1979, *Astrophys. J. Letters* **230**, L153
Zamorani, G., Henry, J.P., Maccacaro, T., Tananbaum, H., Soltan, A., Avni, Y., Liebert, J., Stocke, J., Strittmatter, P.A., Weymann, R.J., Smith, M.G., Condon, J.J.: 1981, *Astrophys. J.* **245**, 357