A Discrete Source Model of the Microwave Background

Article *in* Monthly Notices of the Royal Astronomical Society · July 1974

DOI: 10.1093/mnras/168.1.45P

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Mon. Not. R. astr. Soc. (1974) **168**, *Short Communication*, 45P–50P.

A DISCRETE SOURCE MODEL OF THE MICROWAVE BACKGROUND

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(Received 1974 June 21)

SUMMARY

An interpretation of the microwave background is given in terms of Seyfert and active galaxies in a low-density Universe. At early epochs ($z \sim 100$) all galaxies would have been strong emitters in the submillimetre region of the spectrum. As time proceeds the probability of a galaxy being an emitter, and the strength of the emission from those galaxies alight, decline until at the present epoch about 1 per cent of galaxies, the Seyfert galaxies, are alight. The background spectrum would differ from a 2·7 K blackbody only at wavelengths below 3 mm. The model could be ruled out if Pariskij's upper limit on background fluctuations is confirmed or slightly strengthened.

INTRODUCTION

I give here a discrete source model of the microwave background. Unlike previous models (Wolfe & Burbidge 1969; Smith & Partridge 1970; Setti & Woltjer 1970) this model satisfies all of the following conditions:

(i) A 2·7 K blackbody curve is mimicked for $\lambda \geqslant 3$ mm. For shorter wavelengths than this, the departures from a blackbody curve are consistent with present upper limits.

(ii) The model is consistent with the latest upper limits on fluctuations in the background.

(iii) The population of sources postulated, Seyfert and active galaxies, has actually been detected at submillimetre wavelengths.

(iv) The number-density of sources does not at any epoch exceed that of galaxies.

(v) The energy requirements per galaxy over all epochs, $1 \cdot 4 \times 10^{62}$ erg, although large, is not totally implausible.

INGREDIENTS OF THE MODEL

The ingredients of the model are:

(a) A population of sources, Seyfert and active galaxies, with number-density at the present epoch about 1 per cent of all galaxies

$$\eta_0 = 10^{8 \cdot 3} \text{ per } (c/H_0)^3 \tag{1}$$

where H_0, the Hubble constant, is taken as 50 km s^{-1} Mpc^{-1}.

(b) The monochromatic luminosity of the sources at 1 mm is taken to be

$$P(1 \text{ mm}) = 10^{22 \cdot 5} \text{ W Hz}^{-1} \text{ sr}^{-1} \tag{2}$$

at the present epoch.

Seyfert and related galaxies have been found to be strong infrared emitters (Rieke & Low 1972), which must presumably peak somewhere in the range 30–300 μ in order to be consistent with the lower fluxes found at 3 mm. Evidence for strong emission at 1 mm with positive spectral index in Seyfert's and other active galaxies has been given by Clegg, Ade & Rowan-Robinson (1974). The adopted luminosity (2) is consistent with present available fluxes and upper limits, although an appreciable dispersion about this mean value is likely.

(c) The spectrum of the sources has been assumed to be of the simple form used by Wolfe & Burbidge (1969)

$$P(\nu) \propto \nu^2, \quad \nu \leqslant \nu_m \qquad (3)$$
$$\propto \nu^{-2}, \quad \nu > \nu_m.$$

(d) The Milne (Special Relativity) model has been used. This is a good approximation to a low density $\Lambda = 0$ Universe with matter. And if the microwave background is due to sources, the evidence that General Relativity applies on a cosmological scale is not compelling, so the Milne model is a reasonable one to fall back on. Smith & Partridge (1970) pointed out the advantages of using an open ($k = -1$) Universe for discrete source models of the background.

(e) Since galaxies take at least 10^8 yr to form, it has been assumed that no sources are alight for $z > 100$.

(f) Strong (and carefully chosen) evolution in the properties of the source population is the crux of the present model. At earlier epochs the luminosity of the sources is assumed to be multiplied by a factor $\phi_L(z)$, and the (comoving) number-density by a factor $\phi_D(z)$. The integrated background is then proportional to (Rowan-Robinson & Fabian 1974)

$$\chi(\nu) = \int_{Z=1}^{\infty} \phi(z) . \frac{P_0(\nu Z)}{P_0(\nu)} . Z^{-2}\, dZ \qquad (4)$$

where $\phi(z) = \phi_L(z)\phi_D(z)$ and $Z = 1+z$.

This will exactly mimic a blackbody curve of temperature T, for $\nu < \nu_m$, if

$$\phi(z) = \frac{\nu_2}{\nu_m} \exp\left(\frac{\nu_m}{\nu_2}\right) Z^{-2} \frac{[\exp(\nu_m/Z\nu_2)\{\nu_m/Z\nu_2 - 1\} + 1]}{[\exp(\nu_m/Z\nu_2) - 1]^2} \qquad (5)$$

where $\nu_2 = kT/L$, but this would be an excessively complicated piece of deception on the part of discrete sources, so I have adopted

$$\phi_{L,D}(z) = Z^n \exp Q(1 - 1/Z), \quad Z < 100 \qquad (6)$$
$$= 0, \quad Z > 100.$$

PREDICTIONS OF THE MODEL

(1) *The background spectrum*

The choice of parameters

$$\alpha = 2, \quad \log_{10} \nu_m(\mathrm{Hz}) = 12{\cdot}25, \quad n_L + n_D = -3/2, \quad Q_L + Q_D = 14 \qquad (7)$$

gives a background closely mimicking a 2·7 K blackbody for $\lambda \geqslant 3$ mm (Fig. 1). At 1 mm the excess is 0·25 in $\log_{10} F$, corresponding to an equivalent blackbody temperature of 3·0 K. The predictions of the model are compared with recent observations in Table I.

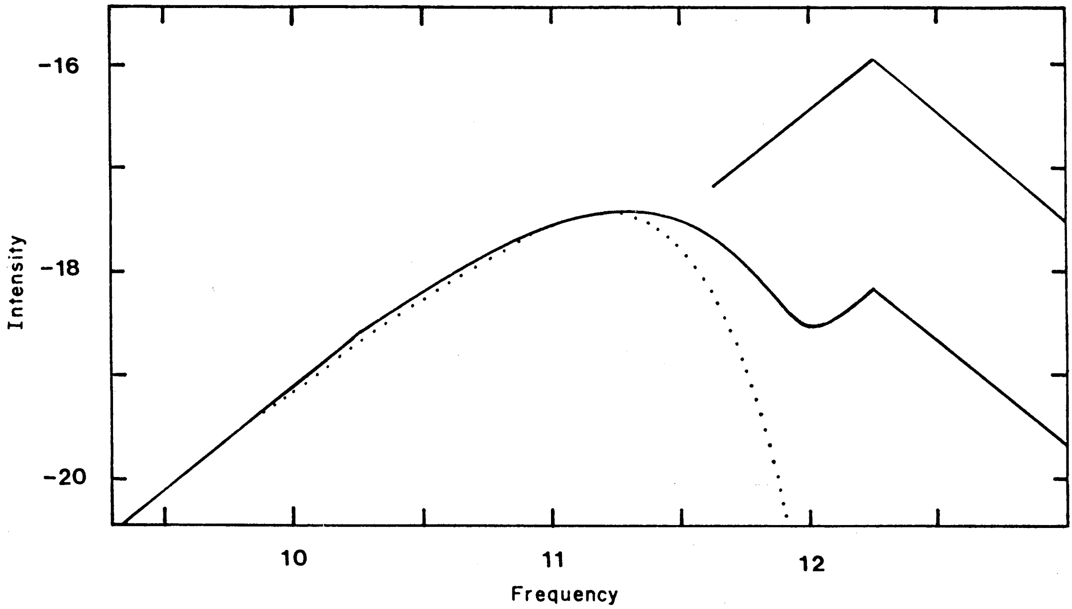

FIG. 1. *Predicted integrated background intensity,* $\log_{10} F(\nu)$, *against* $\log_{10} \nu$ *for discrete source model (continuous line) compared with a 2·7 K blackbody curve (dotted line). Also shown (inset) is the spectrum of an individual source (arbitrary vertical scale).*

TABLE I

Comparison of the predictions of the model with some recent observations of the integrated background

Wavelength	Prediction (K, unless stated)	Observation	Reference
3·3 mm	2·7	$2{\cdot}48^{+0{\cdot}50}_{-0{\cdot}54}$	Boynton & Stokes (1974)
1·32 mm	2·9	$2{\cdot}9^{+3{\cdot}4}_{-2{\cdot}1}$	Hegyi, Traub & Carleton (1972)
0·8–6 mm	2·9	$3{\cdot}1^{+0{\cdot}5}_{-2{\cdot}0}$	Blair *et al.* (1971)
0·87–10 mm	2·8	$2{\cdot}55^{+0{\cdot}25}_{-0{\cdot}45}$	Muehlner & Weiss (1973)
0·74–10 mm	2·9	$2{\cdot}45^{+0{\cdot}45}_{-1{\cdot}05}$	Muehlner & Weiss (1973)
0·54–10 mm	3·0	$2{\cdot}75^{+0{\cdot}8}_{-2{\cdot}75}$	Muehlner & Weiss (1973)
0·3–6 mm	3·15	$3{\cdot}8^{+1{\cdot}0}_{-3{\cdot}8}$	Williamson *et al.* (1973)
0·4–1·3 mm	$1{\cdot}0 \times 10^{-10}$ W cm^{-2} sr^{-1}	$1{\cdot}2 \pm 2{\cdot}0 \times 10^{-10}$ W cm^{-2} sr^{-1}	Houck *et al.* (1972)
85–115 μ	$2{\cdot}0 \times 10^{-11}$ W cm^{-2} sr^{-1}	$\leqslant 6 \times 10^{-11}$ W cm^{-2} sr^{-1}	Houck *et al.* (1972)

The value of α has almost no effect for $\lambda \geqslant 1$ mm, but has been chosen to give consistency with Smith & Roach's (1968) upper limit on the integrated background visible light from galaxies, and with the integrated X-ray background.

The radio luminosities of Seyferts can not be undergoing the evolution (7), due to the integrated radio background limit.

(2) *Background fluctuations*

These can be shown to be

$$\delta \equiv \frac{\langle \Delta I^2 \rangle^{1/2}}{I} = \Omega^{-1/2} \eta_0^{-1/2} \zeta^{1/2} \chi^{-1} \tag{8}$$

where

$$\zeta = \int_{Z_{\min}}^{\infty} \frac{4\phi_L^2(z)\, \phi_D(z) \{p(\nu Z)/p(\nu)\}^2 Z^{-1}\, dZ}{(Z^2-1)^2}, \tag{9}$$

$Z_{\min}$ is the redshift of the nearest source, taken as 1·001 for Seyferts, and Ω is the beam solid-angle of the telescope (e.g. Rowan-Robinson & Fabian 1974).

The choice of parameters, consistent with (7),

$$n_L = \tfrac{1}{2}, \quad n_D = -2, \quad Q_L = 0, \quad Q_D = 14 \tag{10}$$

gives the fluctuations shown in Fig. 2, as a function of frequency, consistent with present observational limits. A Gaussian with half-power beam-width of 2′·8 has been assumed for Pariskij's data. In a recent erratum, Pariskij (1974) has raised this upper limit by a factor of 6.

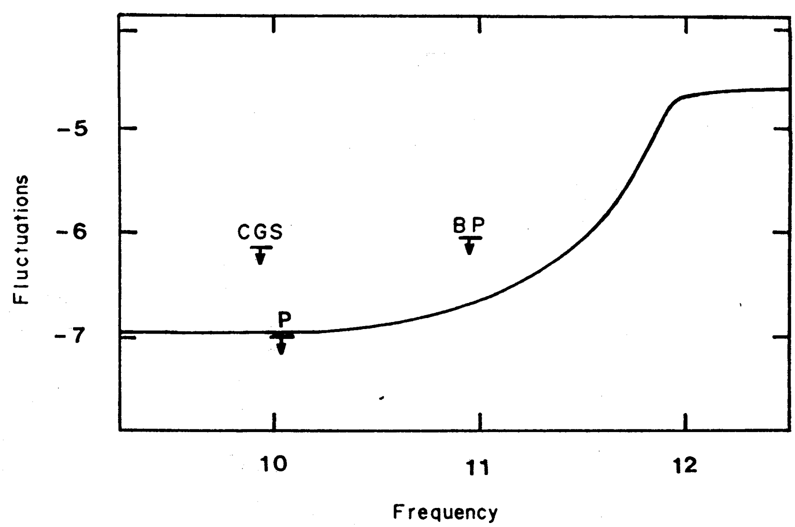

FIG. 2. *Log*$_{10}$ $(\delta\Omega^{1/2})$ *against log*$_{10}$ ν *for discrete source model, compared with observed upper limits: BP = Boynton & Partridge* (1973), *CGS = Carpenter, Gulkis & Sato* (1973), *P = Pariskij* (1973).

(3) *Total energy per galaxy*

The parameters given by (10) imply that all galaxies were strong submillimetre sources at $Z = 100$, with a luminosity 10 times that given by (2) and (3). Since then the probability of a galaxy being alight, and the luminosity when alight, have declined until at the present epoch 1 per cent of all galaxies, the Seyferts, are shining at precisely the luminosities we see them at.

The total energy radiated per galaxy is given by first integrating (2) and (3) over all frequencies, to give a luminosity of $10^{44 \cdot 1}$ erg s^{-1} for sources alight at the present epoch. This must be weighted by the luminosity evolution factor $\phi_L(z)$

and the probability of a galaxy being alight $\phi_D(z)/\phi_D(100)$, and then integrated over time, to give $10^{62\cdot15}$ erg per galaxy, a large but not impossible requirement from each galaxy.

(4) *Source counts*

Very steep source counts are predicted at faint fluxes, illustrated in Fig. 3 for a wavelength of 1 cm. For $1 < z < 10$, $d \log N/d \log S \sim -6$, but it is doubtful if this prediction of the model can be tested in the foreseeable future. However, at 1 mm the number of sources on the whole sky brighter than 10 fu is predicted to be 12, and brighter than 3 fu to be 70. These are on the brink of detectability with existing techniques.

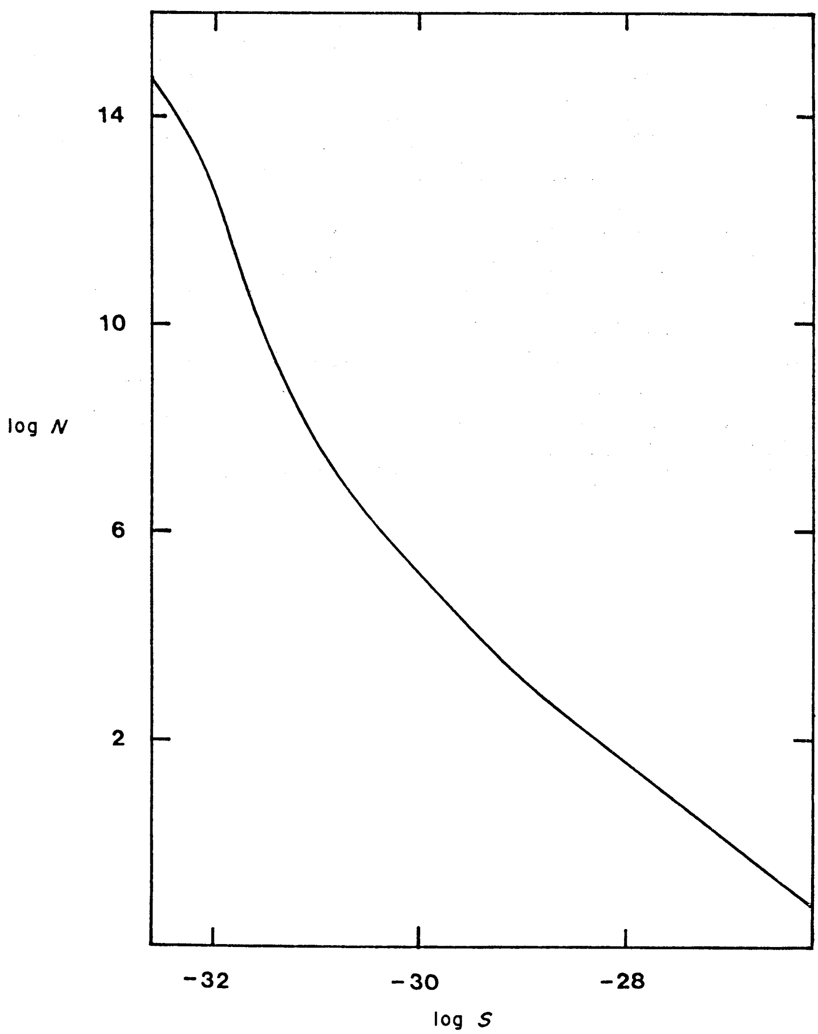

FIG. 3. *Source counts at a wavelength of 1 cm, according to discrete source model of present paper.* $\mathit{Log}_{10}\, N(sr^{-1})$ *against* $\mathit{log}_{10}\, S(W\, m^{-2}\, Hz^{-1})$.

(5) *Crucial tests*

Only slight improvements in the limit on fluctuations would make survival difficult for this type of model. The strongest test will be the measurement of the spectrum of the background, and of individual sources, near 1 mm.

ACKNOWLEDGMENT

I am grateful to one of the editors, whose criticisms led to a considerable improvement in the clarity of presentation of this paper.

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Received in original form 1974 *April* 1

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