X-602-76-274

PREPRINT

NASA TM X- 71254

THE COSMIC FAR-INFRARED BACKGROUND AT HIGH GALACTIC LATITUDES

(NASA-TM-X-71254) THE COSMIC FAR-INFRARED BACKGROUND AT HIGH GALACTIC LATITUDES (NASA) 16 p HC A02/MF A01 CSCL 03B

N77-15973

Unclas

G3/93 12470

F. W. STECKER

J. L. PUGET

G. G. FAZIO

DECEMBER 1976

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

X-602-76-274

PREPRINT

NASA TM X- 71254

THE COSMIC FAR-INFRARED BACKGROUND AT HIGH GALACTIC LATITUDES

(NASA-TM-X-71254) THE COSMIC FAR-INFRARED BACKGROUND AT HIGH GALACTIC LATITUDES (NASA) 16 p HC A02/MF A01 CSCL 03B

N77-15973

Unclas
G3/93 12470

F. W. STECKER
J. L. PUGET
G. G. FAZIO

DECEMBER 1976

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

THE COSMIC FAR-INFRARED BACKGROUND AT HIGH GALACTIC LATITUDES

F. W. Stecker
Theoretical Studies Group
NASA Goddard Space Flight Center

J. L. Puget
Observatoire de Meudon

G. G. Fazio
Center for Astrophysics

THE COSMIC FAR-INFRARED BACKGROUND AT HIGH GALACTIC LATITUDES

F. W. Stecker
Theoretical Studies Group
NASA Goddard Space Flight Center

J. L. Puget
Observatoire de Meudon

G. G. Fazio
Center for Astrophysics

ABSTRACT:

We predict far-infrared background fluxes from various cosmic sources. These fluxes lie near the high frequency side of the blackbody radiation spectrum. These sources could account for a significant fraction of the background radiation at frequencies above 400 GHz which might be misinterpreted as a "comptonization" distortion of the blackbody radiation. Particular attention is paid to the possible contributions from external galaxies, rich clusters of galaxies and from galactic dust emission.

I. INTRODUCTION

The emerging field of infrared astronomy brings the promise of throwing new light on some important ongoing problems of cosmology and galactic and extragalactic astrophysics. Detector technology has reached the stage where various background fluxes should be measurable. We predict and discuss the origin and spectra of such fluxes and their astrophysical implications.

II. FAR-INFRARED EMISSION FROM EXTERNAL GALAXIES

The contribution of young galaxies to the visible and infrared background radiation was investigated by Partridge and Peebles (1967). According to recent work on nucleosynthesis and the chemical evolution of galaxies (Audouze and Tinsley 1976) and observations of chemical abundance gradients in our Galaxy and others (Peimbert 1975), nuclei with $A \geq 6$ as well as 25% of the He have been synthesized in stars. This implies an energy production of $\sim \frac{1}{2}$ MeV per nucleon which we assume to have undergone nucleosynthesis. The energy production over one Hubble time calculated using an average visible mass density of 4×10^{-31} g/cm^3 is an order of magnitude lower than the $\frac{1}{2}$ MeV/nucleon implied by the nucleosynthesis argument given above. This is consistent with the argument that data on the chemical evolution of our galaxy requires a generation of massive stars occurring at a redshift z near z_{max} (the maximum redshift at which galaxies existed) corresponding to an epoch when most of the elements with $A \geq 6$ were produced. Partridge and Peebles (1967) therefore assumed strong time evolution of galaxy luminosity with most of the energy production occurring in early generations of massive stars which radiate mainly in the ultraviolet. We want here to reconsider this "ultraviolet" hypothesis. Recent theoretical and observational work on the far-infrared diffuse galactic emission (Ryter and Puget 1976, Rouan, et al. 1976, Serra, Puget and Ryter 1976) has indicated that the energy output in the Galaxy in the far-infrared may be comparable to the energy output in the visible. This may not be unreasonable since the massive molecular clouds in which stars are formed have large visible extinction ($A_V>10$). For massive stars with a lifetime less than or equal to the lifetime of the molecular clouds in which they are embedded, most of the energy emitted will be absorbed by dust grains and reemitted in the infrared. A large fraction of elements with $A\geq 6$ may be in grains (Aannestad and Purcell 1973) in which case, the optical depth in the clouds could be large even near z_{max} when the heavy element abundances are an order of magnitude lower than the standard abundances.

If L_0 is the present mean far-infrared luminosity of galaxies and if we assume a luminosity evolution with redshift of the form $L(z)=L_0(1+z)^\alpha$ and if we also restrict α and z_{max} by the requirement that the energy per nucleon emitted in the infrared is near the amount generated by nucleosynthesis, i.e. ½ MeV/nucleon, the total energy density in the far-infrared background from galaxies will be given by

$$u_{IR} = 0.1 \frac{\alpha-1}{\alpha-2} (1+z_{max})^{-1} \text{ eV cm}^{-3} \qquad (1)$$

For $3 \leq z_{max} \leq 10$, the energy density in the background radiation at present will then be $\sim (1\text{-}3)\times 10^{-2}$ eV cm^{-3}.

The dust temperature which determines the position of the peak in the source spectrum is a weak function of galaxy luminosity ($T \propto L^\kappa$, $\kappa \leq 0.2$)

At the time when most of the energy was emitted, the average luminosity per unit mass of dust was at least an order of magnitude greater than what it is at present in our own galaxy. We therefore assume that the source spectrum peaks at a frequency approximately a factor of 2 higher than at present.

The spectrum $i(\nu)$ of young galaxies will then be an integral over different dust temperatures peaking at $\nu_g \sim 4000$ GHz which can be approximated by two power laws corresponding to spectral indeces of 4 for $\nu < \nu_g$ and -2 for $\nu > \nu_g$.

Assuming that the infrared luminosity at present is comparable to the visible luminosity, $N_0 L_0 = 2.2\times10^{-10}$ solar luminosity units ($\mathcal{L}_\odot$) per pc^3 (Allen 1973) where N_0 is the present number density of galaxies in the universe at present and L_0 their mean luminosity, we consider the two extreme cases for our model calculations:

I: $\alpha=3$, $z_{max}=2.1$, $N_0 L_0=3.5\times10^{-10}\mathcal{L}_\odot pc^{-3}$

II: $\alpha=2$, $z_{max}=8.4$, $N_0 L_0=1.8\times10^{-10}\mathcal{L}_\odot pc^{-3}$

again restricting α and z_{max} so that the total energy released is ½MeV/nucleon. The total background spectrum from galaxies is then

$$I(\nu)=\frac{c}{4\pi H_0} N_0 \int_0^{z_{max}} dz\, i[\nu(1+z)]\,(1+z)^{\alpha-2}(1+\Omega z)^{-\frac{1}{2}} \qquad (2)$$

Using equation (2), one obtains for cases I and II the spectra $J_\nu=\nu I(\nu)$ shown in figure 1. Also shown in the figure is the curve III given for the case where there is no evolution and consequently the energy per nucleon ending up in the far infrared is must less than ½MeV/nucleon. These curves can be compared with the <u>sum</u> of the three curves for galaxies, Seyferts and quasars given by Puget, Stecker and Bredekamp (1976)[1] Curves I and II are in a strict sense upper limits, since they assume that <u>all</u> of the energy from nucleosynthesis ends up in the far-infrared.

---

[1]These results are interestingly similar to those obtained from the models extropolated from Seyfert galaxy observations suggested by Low and Tucker (1968).

III. EMISSION FROM RICH CLUSTERS

It has recently been pointed out by Pustil'nik (1975) that rich galaxy clusters may be an important source of detectible infrared radiation from intracluster dust. Although there exist serious theoretical questions about the survival of such dust and its cooling time (Silk and Burke 1974) evidence for its existence comes from studies of its implied extinction through counts of galaxies behind nearby clusters (Karachentsev and Lipovetskii 1968). Other evidence for the existence of intracluster dust has been summarized by Schmidt (1976) and is made more plausible by the detection of iron line emission at 7 keV from intergalactic gas in Virgo, Perseus and Coma clusters. The existence of iron in this intracluster gas implies that a significant fraction of it came from the cluster galaxies, rather than from a primodial cosmic medium (Mitchell, et al. 1976, Serlemitsos, et. al. 1976).

Since it now appears that the intracluster gas is radiating thermal bremsstrahlung x-rays and is at a temperature of $\sim 10^8$K (Gull and Northover 1976, Pariiskii 1972, Sheepmaker et al. 1976, Serlemitsos et al. 1976), collisions of the electrons and ions in this hot plasma with the dust grains would provide the dominant cooling mechanism for the gas. Pustil'nik (1975), using Ostriker and Silk's (1973) estimate of the cooling rate of the gas due to grain collision and thermal bremsstrahlung, has obtained an estimated ratio of infrared luminosity from grains to x-ray luminosity from bremsstrahlung $L_{IR}/L_X \simeq 700$.

The temperature of the grains is calculated by Pustil'nik (1975) to be 30K and is insensitive to variations in the gas density, since $T_g \propto n^{1/5}$ for an assumed emissivity law $Q_{IR} \propto \nu$. In the following calculations, we adopt Pustil'nik's values of $L_{IR}/L_X = 700$ and $T_g = 30$K.

In order to calculate the background infrared flux from all rich clusters, we assume a value for the Hubble parameter of $H_o = 50$ km s^{-1} Mpc^{-1}. Using Abell's (1976) estimate of 4000 Abell clusters within 1200 Mpc, one obtains a mean cluster density at present of 2×10^{-74} m^{-3}. From Kellogg's (1974) compilation of nearby cluster x-ray sources, we estimate a mean x-ray luminosity per rich cluster of $L_x \sim 2 \times 10^{37}$w which converts to an infrared luminosity per cluster of $L_{IR} \simeq 1.4 \times 10^{40}$ w, using Pustil'nik's ratio. The resulting background flux from clusters, neglecting cosmological effects, is then of the order of

$$I_B \simeq \frac{n_o c}{4\pi H_o} \; L_{IR} \;\simeq 4 \times 10^{-9} \;\; wm^{-2} \;\; Sr^{-1} \tag{3}$$

with a spectral distribution, assuming $Q_{IR} \propto \nu$, of

$$I_B(\nu) \;\propto\; \frac{\nu^4}{e^{\nu/\nu_g}-1} \tag{4}$$

with $\nu_g = \dfrac{kT_g}{h} \;\; \simeq \;\; 630$ GHz

The peak in the non-redshifted spectral distribution occurs at frequency

$$\nu_{max} \simeq 2500 \text{ GHz} \tag{5}$$

The spectral distributions plotted in figure 1 for infrared backgrounds from various high galactic latitude sources are given in terms of the function $J_\nu = \nu I_\nu$. Using this definition

$$J_{\nu,\text{ clusters}} \;\simeq 1.6 \times 10^{-10} \;\; \frac{(\nu/\nu_g)^5}{e^{\nu/\nu_g}-1} \;\; wm^{-2} \; sr^{-1} \tag{6}$$

The effect of sources at high redshifts with an evolution redshift dependence factor $(1+z)^\alpha$, is determined by the relation

$$J_{\nu,\text{ clusters}} = 1.6 \times 10^{-10} \left(\frac{\nu}{\nu_g}\right)^5 \int_0^{z_m} dz\,(1+z)^{2+\alpha}(1+\Omega z)^{-\frac{1}{2}}\left\{\exp\left[(1+z)\frac{\nu}{\nu_g}\right]-1\right\}^{-1} \tag{7}$$

where z_m is the maximum redshift at which the cluster sources exist. The spectral function J_ν evaluated using equation (7) with $\alpha = 3$ and $z_m = 2$ and 4 is then shown in figure 1.

IV. GALACTIC EMISSION

In comparing infrared fluxes from various extragalactic background sources, it is important to notice that emission from dust in our galaxy at high galactic latitudes can be quite significant. If, for example, we take for the average column density of HI gas perpendicular to the galactic plane a value of $N = 3 \times 10^{20}$ cm^{-2} (Falgarone and Lequeux 1973) and a grain density $N_g = 1.4 \times 10^{-13} N_H$ (Fazio and Stecker 1976), the mean absorption in the blue is calculated to be $A_B \approx 0.17$ mag, consistent with the values obtained by galaxy count studies (Hubble 1934, Shane and Wirtanen 1954, de Vaucouleurs and Malik 1969) and that most recently obtained by Rubin et al. (1976) of $A_B \approx 0.15 \pm 0.03$. Using the parameters given by Fazio and Stecker (1976) with $T_g = 15$K, one obtains the flux estimate labeled "mean galactic high latitude dust emission" shown in figure 1. In this calculation we assume for absorption at optical wavelengths a grain albedo of 0.5 (Witt and Lillie 1973) and a low optical depth for the hydrogen clouds at high latitudes. This is tantamount to assuming that we are looking between dark clouds. This flux is much below that predicted for the dark cloud component by Ryter and Puget (1976) and apparently supported by recent measurements (Rouan et al. 1976, Serra, Puget and Ryter 1976). One should thus avoid regions of dark clouds when making measurements of far-infrared background fluxes. Figure 1, however, represents only a mean value for galactic dust emission. Significant portions of the sky near the galactic poles may be almost totally free of dust and gas (Shane and Wirtanen 1954, Heiles and Jenkins 1975) and therefore almost free of galactic infrared emission. In any case, the galactic high latitude emission should be much spottier than the extragalactic emission, which, together with spectral differences, should help in separating the two components. It should also be noted that emission from higher temperature interplanetary dust should dominate even far out of the ecliptic above 10^4 GHz. An estimate of this emission based on measurements of D. A. Briotta (thesis) and assuming $Q_{IR} \propto \nu$ is shown in figure 1.

IV. DISCUSSION

Aside from the interesting questions which studies of the extragalactic infrared emission will help answer about the distribution and evolution of various extragalactic objects and clusters, it is important to be aware that such emission could complicate future searches for high frequency distortions of the blackbody background expected from "comptonization" processes (Komponeets 1957, Zel'dovich, Ilarinov and Sunyaev 1972, Chan and Jones 1975). Such distortions are caused by energy input following the recombination epoch in big-bang cosmology and studies of them can provide valuable information about galaxy formation processes and possible annihilation processes in Baryon symmetric cosmologies (Stecker and Puget 1972, 1973; Ramani and Puget 1976, Aldrovandi and D'Olival 1976). It may require a rather difficult spectral analysis to distinguish between a true high-frequency blackbody distortion and emission from sources such as distant galaxies and galaxy clusters which may appear to mimic such a distortion. It is also important to take note of the effect of such background emission on the propagation of ultrahigh energy cosmic rays in intergalactic space (Stecker 1968, 1969; Puget, Stecker and Bredekamp 1976).

A crucial test of whether the diffuse background from distant clusters exists in the detection of far-infrared radiation from one or more of the clusters of galaxies that emit x-radation. Using the fluxes of Pustil'nik (1975) the average x-ray core radii as reviewed by Malina et al. (1976), and assuming that the infrared radiation comes from the core, we note that, with existing balloon born telescopes having a beam width of 15' it should be possible to detect the Perseus and Coma clusters with signal-to-noise ratios of at least 10:1 using a one-second integration time. We strongly recommend that such observations be performed. Even a negative result would be important in determining whether dust exists in clusters of galaxies and whether one should expect a significant background from distant clusters on the high-frequency side of the blackbody radiation.

With regards to the problem of observing young galaxies one should note that they might show up more as far infrared sources then as near infrared sources as suggested by Peebles and Partridge (1967).[2]

It can be seen from figure 1 that the best frequency range for observing the extragalactic far-infrared background radiation is between 600 GHz and 10^4 GHz.

We wish to thank Dr. J. E. Felten and Dr. M. G. Hauser for helpful discussions of this paper.

[2]This idea has also recently been discussed by Kaufman (1976).

Aanestad, P. A. and Purcell, E. M. 1973, Annual Review of Astron. and Ap., 11, 309.

Abell, G. O. 1976, Galaxies and the Universe (ed. A. Sandage, M. Sandage and J. Kristian) U. Chic. Press, Chicago, Ch. 18.

Aldrovandi, R. and D'Olival J. B. S. 1976, Ap. and Space Sci. 44, 471.

Audouze, J., Tinsley, B. 1976, Ann. Rev. Astron. Ap. 14, 43.

Chan, K. L. and Jones, B. J. T. 1975, Ap. J. 195, 1.

Falgarone, E. and Lequeux, J. 1973, Astron. and Ap. 25, 253.

Fazio, G. G. and Stecker, F. W. 1976, Ap. J. Letters 207, L49.

Gull, S. F. and Northover, K. J. E. 1976, Nature 263, 572.

Heiles, C. and Jenkins, E. B. 1976, Astron. and Ap. 46, 333.

Hubble, E. 1934, Ap. J. 67, 321.

Karachentsev, I. D. and Lipovetskii, V. A. 1968, Astron. Zh. 45, 1148 (Sov. A. J. 12, 909).

Kaufman, M. 1976, Ap. and Space Sci. 40, 369.

Kellogg, E. M. 1974, X-ray Astronomy (ed. R. Giacconi and Gursky) Reidel Pub. Co., Dordrecht, pg. 321.

Komponeets, A. S. 1956, Zh. Eksperi, Teoret. Fiz. 55, 278, (JETP 4, 730).

Low, F. J. and Tucker, W. H. 1968, Phys. Rev. Letters 21, 1538.

Malina, R., Lampton, M. and Bowyer, S. 1976, Ap. J. 209, 678.

Mitchell, R. J., Culhane, J. L., Davidson, P. J. N. and Ives, J. C. 1976, Mon. Not. R. Astron. Soc. 176, 29.

Ostriker, J. P. and Silk, J. 1973, Ap. J. Letters 184, L113.

Pariiskii, Yu. N. 1972, Astron. Zh. 49, 1322, (Sov. A. J. 16, 1048).

Partridge, R. B., and Peebles, P. J. E., 1967, Ap. J. 148, 377.

Peimbert, M. 1975, Ann. Rev. Astron. Ap. 13, 113.

Puget, J. L., De Boer K., Wijnbergen, J., Serra, G., Puget, J. L., Ryter, C. 1976, preprint.

Puget, J. L., Stecker, F. W. and Bredekamp, J. H. 1976, Ap. J. 205, 638.

Pustil'nik, S. A. 1975, Pis'ma Astron. Zh. 1, 8, (Sov. Astron. Lett. 1, 49).

Ramani, A. and Puget, J. L. 1976, Astron. and Ap. 51, 411.

Rouan, D., Lena, P. J., 1976, Ap. J. Lett. in press.

Rubin, V. C., Ford, W. K., Thonnard, N., Roberts, M. S. and Graham, J. A. 1976, Astron. J. 81, 687.

Ryter, C. and Puget, J. L. 1976, preprint.

Schmidt, K. H. 1976, Solid State Astrophysics (ed. N. C. Wickramasinghe and D. J. Morgan) Reidel Pub. Co., Dordrecht, Holland.

Serlemitsos, P. J., Smith, B. W., Boldt, E. A., Holt, S. S. and Swank, J. H. 1976, Ap. J. Letters, in press.

Shane, C. D. and Wirtanen, C. A. 1954, Astron. J. 59, 285.

Sheepmaker, A., Ricker, G. R., Brecher, K., Ryckman, S. G., Ballatine, J. E., Doty, J. P., Downey, P. M. and Lewin, W. H. G. 1976, preprint.

Silk, J. and Burke, J. R. 1974, Ap. J. 190, 11.

Stecker, F. W. 1968, Phys. Rev. Letters 21, 1016.

Stecker, F. W. 1969, Phys. Rev. 180, 1264.

Stecker, F. W. and Puget, J. L. 1972, Ap. J. 178, 57.

Stecker, F. W. and Puget, J. L. 1973, Gamma Ray Astrophysics (ed. F. W. Stecker and J. I. Trombka) NASA SP-339, U. S. Govt. Printing Office, Washington, D. C., pg. 381.

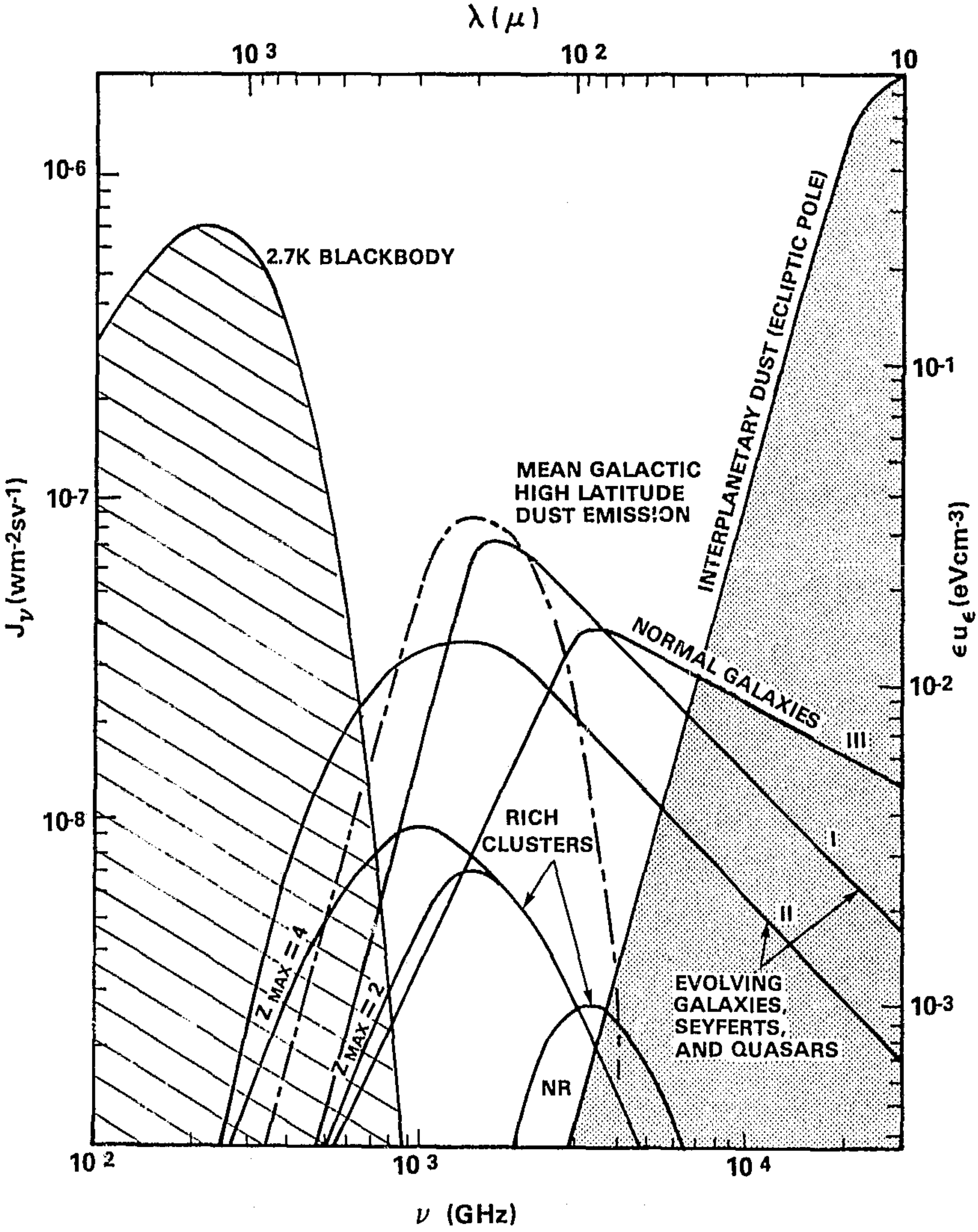
Vaucouleurs, G. de and Malik, G. M. 1969, Mon. Not. R. Astron. Soc. 142, 387.

Witt, A. N. and Lillie, C. F. 1973, Astron. and Ap. 25, 397.

Zel'dovich, Ya. B., Illarionov, A. F., and Sunyaev, R. A. 1972, Zh. Eksperi, Teoret. Fiz. 62, 1217, (JETP 35, 643).

Figure Caption:

Far-infrared background fluxes from various cosmic sources as described in the text. The curve marked "clusters (N.R.)" is the estimate of the contribution from rich clusters, neglecting redshift and other relativistic cosmological effects (eq. 6). The other estimates for rich clusters are made using eq. (7) with $\alpha = 3$.



λ (μ)
10 3
10 2
10
10-6
10-7
10-8
10-1
10-2
10-3
2.7K BLACKBODY
MEAN GALACTIC
HIGH LATITUDE
DUST EMISSION
INTERPLANETARY DUST (ECLIPTIC POLE)
NORMAL GALAXIES
III
I
II
RICH
CLUSTERS
Z MAX = 4
Z MAX = 2
NR
EVOLVING
GALAXIES,
SEYFERTS,
AND QUASARS
Jν (wm-2sv-1)
εuε (eVcm-3)
10 2
10 3
10 4
ν (GHz)

Mailing Addresses:

G. G. FAZIO:	Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02138
J. L. PUGET:	Observatoire de Meudon, 92190, Meudon, France
F. W. STECKER:	Theoretical Studies Group, Code 602, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771