INTENSITY OF THE INFRARED RADIATION FROM INTERSTELLAR GRAINS IN THE SOLAR NEIGHBORHOOD

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Abstract. The expected intensity distribution of the infrared radiation in the solar neighborhood from the grain models of dirty ice, graphite and graphite core-dirty ice mantle has been calculated. It is found that the expected intensity from grain models at 100 μ agrees reasonably well with the observations of Hoffmann and Frederick.

1. Introduction

In recent years there has been growing interest in the study of the far infrared radiation from various astronomical objects. This has been brought about as a result of the successful use of rockets, balloons and satellites. The great interest is also due to the vast improvements that have been obtained in the observation of the infrared region of the spectrum. Already quite a number of important and interesting results have been obtained. We might mention a few results, like the detection of strong infrared continuum in planetary nebulae (Gillett *et al.*, 1967; Gillett and Stein, 1969; see also Krishna Swamy and O'Dell, 1968; Krishna Swamy, 1969) in Seyfert Galaxies (Low and Kleinmann, 1968) in stars (Gillett *et al.*, 1968) and the galaxy (Becklin and Neugebauer, 1968). Recently, Hoffmann and Frederick (1969) have made a measurement in the direction of the galactic center centered at the wavelength of 100 μ (see also Low *et al.*, 1969). The source is almost in the galactic plane and at the galactic center within the uncertainty of the observations.

The importance of applying multiple tests simultaneously to discriminate the various grain models has been emphasized recently by Krishna Swamy and O'Dell (1967a). The application of various tests simultaneously enables one to considerably reduce the ambiguity of the nature of the allowed models. In addition to the already existing tests, one can use the infrared radiation from grains as an additional test (see also Stein, 1966). Therefore, in the present paper we would like to make some detailed calculations of the expected intensity from various grain models as a function of wavelength. We find that the observations of Hoffmann and Frederick (1969) and the expected intensity based on the present calculations agree reasonably well.

2. Infrared Emission from the Grains

The infrared emission from interstellar grains can be calculated, once we know the temperature of the grains. The temperature of the grains in turn is determined by the interstellar radiation that is absorbed at visible and near infrared regions and

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the rate at which the grains can lose energy by radiation. The equation describing this condition is given by (Van de Hulst, 1949)

$$\int_0^\infty F\lambda Q_{\mathrm{abs}}(a, \lambda)\,\mathrm{d}\lambda = \int_0^\infty \pi B(\lambda, T_g)\, Q_{\mathrm{abs}}(a, \lambda)\,\mathrm{d}\lambda, \tag{1}$$

where $Q_{\mathrm{abs}}(a, \lambda)\,\pi a^2$ is the absorption cross-section at wavelength λ, $F\lambda$ is the interstellar radiation field, T_g is the grain temperature and $B(\lambda, T_g)$ is the Planck function. Equation (1) could be solved for T_g provided all the other quantities are specified. Knowing the temperature of the grain the total radiation emitted out by the grains per cm^3 can be calculated from

$$\bar{F}(\lambda) = \int \pi B[\lambda, T_g(a)]\, Q_{\mathrm{abs}}(a, \lambda)\, 4\pi a^2 n(a)\,\mathrm{d}a, \tag{2}$$

where $B[\lambda, T_g(a)]\, Q_{\mathrm{abs}}(a, \lambda)$ is the thermal emissivity of a grain of radius 'a' and temperature T_g. $n(a)$ represents the number of grains in an interval da. Therefore, we have for the total expected intensity

$$I(\lambda) = \bar{F}(\lambda)\, L, \tag{3}$$

where L is the path length in kpc.

A. GRAIN MODELS AND SIZE DISTRIBUTIONS

So far, we discussed the method of calculation of the expected infrared fluxes due to the interstellar grains. For an actual calculation, we have to specify the nature of the grains and their size distribution. Up to date, a large variety of theoretical models for the interstellar grains have been proposed. The principle types of Mie particles that have been proposed are those of dirty ice, iron, graphite and graphite cores with ice mantles. A critical study of the above grain models in relation to the observed properties of the interstellar grains has been done by Krishna Swamy and O'Dell (1967a). They found that out of the above models, graphite core-ice mantle models generally seem to satisfy all of the existing observations (see also Wickramasinghe and Krishna Swamy, 1967; Donn and Krishna Swamy, 1969). In the present paper, we calculate the expected intensities from three grain models, namely those of dirty ice, graphite and dirty ice coated graphite. For purposes of the dirty ice and graphite calculations, we have assumed an Oort and Van de Hulst (1946) size distribution, which gives a best fit with the observed reddening curve (see Krishna Swamy, 1965; Krishna Swamy and O'Dell, 1967a, b). For graphite core ice mantle particles, we do the calculations for a graphite core of 0.05 μ and for the distribution of mantle sizes as given by Wickramasinghe (1965).

B. ABSORPTION CROSS-SECTIONS

For simple particles the absorption cross-section is calculated from the Mie theory (Van de Hulst, 1957) and for composite particles according to Güttler's (1952) theory.

For dirty ice grains the absorption cross-section in the infrared has been calculated using the refractive index data of Kislovskii (1959), and for the visible region we have used $m = n - 0.05\,i$ (Van de Hulst, 1949). The variation of the real part of the refractive index of m with wavelength is taken into account. For graphite grains, we have used for the refractive index the values obtained by Taft and Philipp (1965).

C. INTERSTELLAR RADIATION FIELD

In our calculations, we adopt for the interstellar radiation field the values as obtained by Zimmermann (1964a). The interstellar radiation field as given by Zimmermann is essentially derived by summing the contributions of stars of various spectral types. Although there are some uncertainties involved due to corrections for the interstellar extinction and also to the uncertain stellar flux in the far ultraviolet, it is probably the best available determination of the mean interstellar field (see Lambrecht and Zimmermann, 1955, 1956; Zimmermann, 1964b). In fact, the grain temperatures computed for the Zimmermann's radiation field (Krishna Swamy and Wickramasinghe, 1968) compares well with those obtained by using a black body radiation field of temperature $T = 10^4$ K and with a dilution factor of 10^{-14} (Greenberg, 1963; Stecher and Williams, 1966). Zimmermann has given the interstellar radiation field for various latitudes namely, $0° \leqslant |b| \leqslant 10°$; $10° \leqslant |b| \leqslant 30°$ and $30° \leqslant |b| \leqslant 90°$. He has also given the total interstellar radiation field, which is essentially the sum overall latitudes. In the present paper we calculate the expected intensity from grain models for the above four interstellar radiation fields.

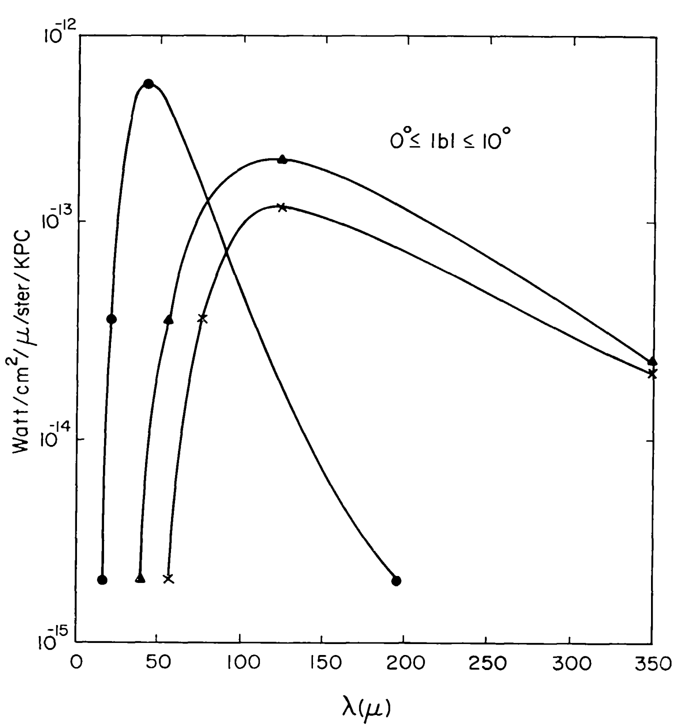

Fig. 1. Calculated spectral distribution of intensities from interstellar grain models of graphite (dots), dirty ice (crosses) and graphite core-dirty ice mantle (triangles) for radiation field $0° \leqslant |b| \leqslant 10°$.

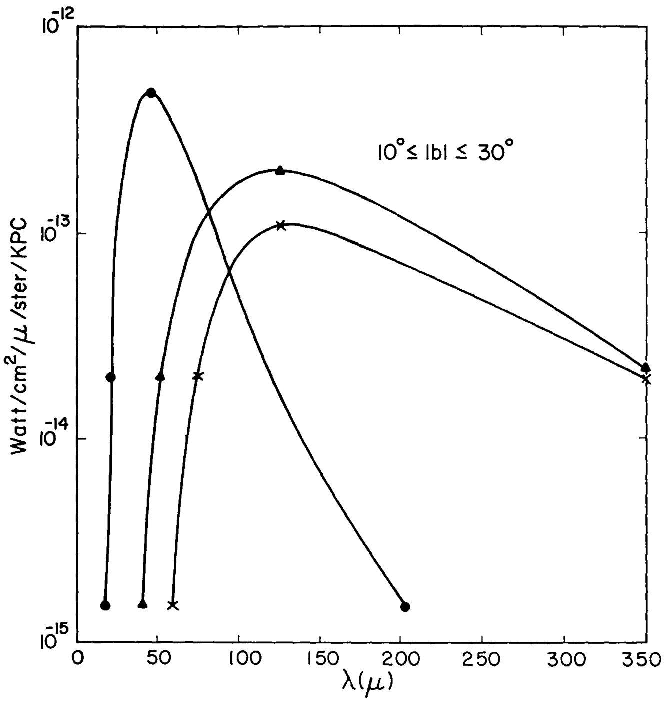

Fig. 2. Same as Figure 1, except for radiation field of $10° \leqslant |b| \leqslant 30°$.

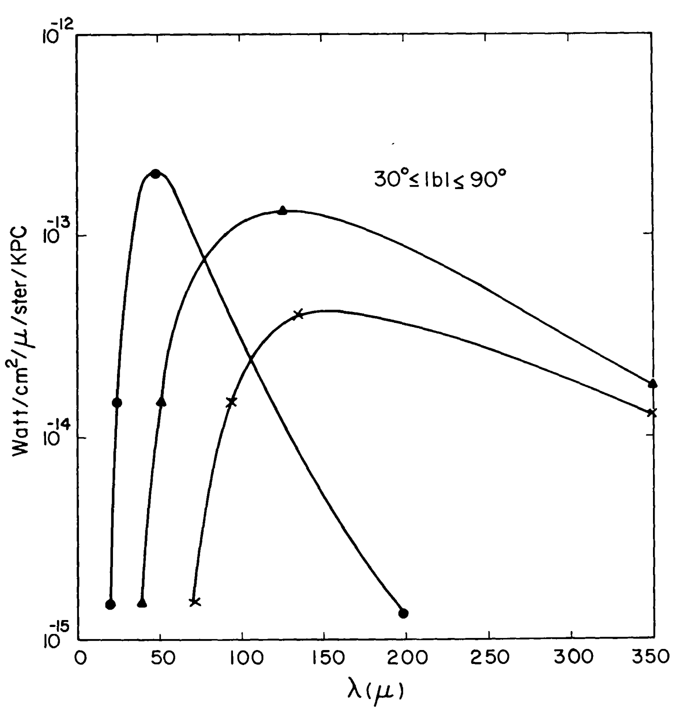

Fig. 3. Same as Figure 1, except for radiation field of $30° \leqslant |b| \leqslant 90°$.

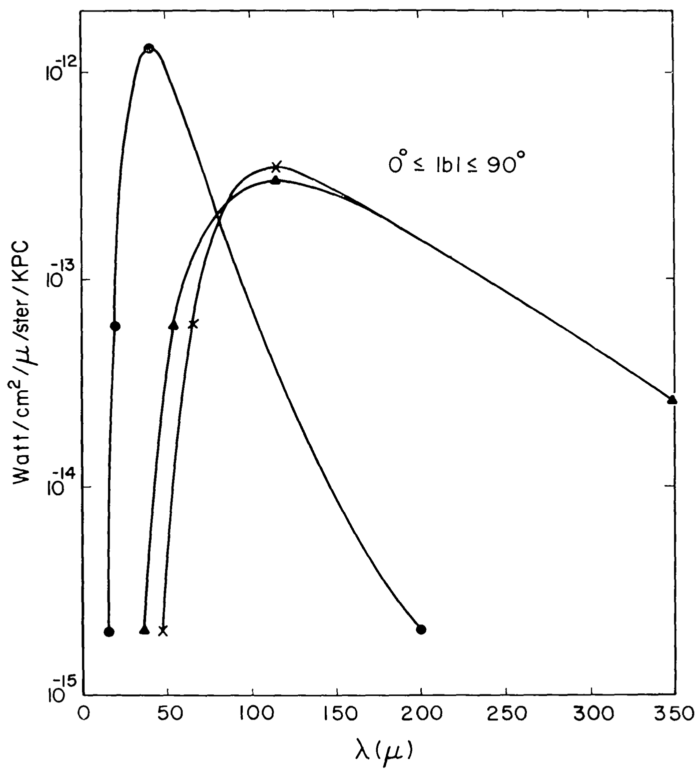

Fig. 4. Same as Figure 1, except for radiation field of $0° \leqslant |b| \leqslant 90°$.

We are now in a position to calculate the temperature of the grains and consequently the expected intensity of the infrared emission from the grains. Hoyle and Wickramasinghe (1967) have suggested that the presence of weakly bound impurity atoms in the grain, may lead to broad absorption bands at $\lambda \sim 1$ mm. The effect of the presence of weakly bound impurity atoms in the grains can enhance the infrared absorption efficiency at $\lambda \sim 1$ mm, and thus lower the temperature of the grain models compared to that of pure grain model (Krishna Swamy and Wickramasinghe, 1968). Recently, Purcell (1969) has examined this problem in some detail and finds that although the cross-section of the grain is increased because of the presence of impurities, but it is not possible to get $Q \simeq 1$. However, for the present paper we use for the grain temperatures the values obtained for pure grain models.

The expected infrared emission from the various grain models and for various interstellar radiation fields is plotted as a function of wavelength in Figures 1–4. It can be seen from these figures that the infrared emission from grains could be used effectively in principle as an additional test in discriminating the types of particles.

3. Comparison with Observations

In order to compare the present results with the observations of Hoffmann and Frederick at 100 μ, we use a path length of 10 kpc. The results are shown in Figure 5.

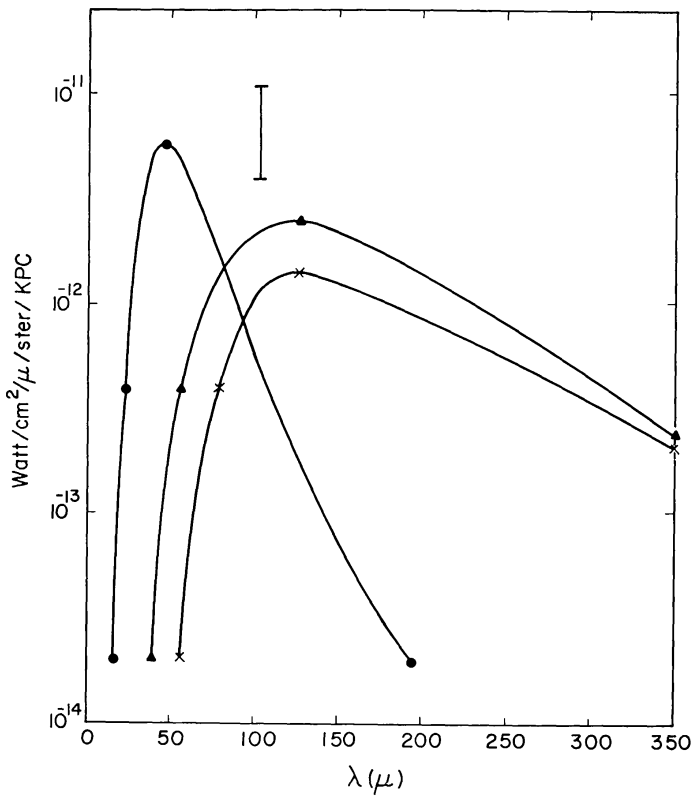

Fig. 5. Comparison of the expected intensities from the galactic center for various grain models with the observations of Hoffmann and Frederick. All the symbols have the same meaning as in Figure 1. The line with bars denotes the observations of Hoffmann and Frederick at 100 μ.

It may be seen that within the uncertainty of observations and calculations, the agreement between the two is good.

4. Discussion and Conclusions

In the present paper, we have calculated the expected intensities from interstellar grain models of dirty ice, graphite and graphite core-dirty ice mantles. The results of the calculations are shown in Figures 1–4. The expected intensity from grain models at 100 μ agrees reasonably well with the observations of Hoffmann and Frederick. Therefore, the infrared flux observed by Hoffmann and Frederick at 100 μ essentially seems to arise from the thermal emission from the grains. Unfortunately, the discrepancy between the observed and the calculated intensities for various grain models at 100 μ is not appreciable to eliminate any type of particle, in view of the uncertainties involved. So what is needed is the observed spectral distribution of the infrared emission. One can then use this as an additional test for discriminating the types of particles. Only in a few cases is it possible to supplement the information derived from light scattering in the visible region of the spectrum with the information obtained from the thermal emission from grains to gain a greater insight concerning the nature of the particle (see Krishna Swamy and Donn, 1968). More observations at shorter and longer wavelengths are needed before one can use the thermal emission from grains as an additional test for discriminating the various existing grain models.

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Note added in proof: Recently there have been some discussions of the possibility of interstellar grains to be made up of silicate material (Knacke *et al.*, 1969; Hoyle and Wickramasinghe, 1969; Donn *et al.*, 1970). The thermal emission from the silicate grain model should be roughly the same as that of dirty ice model.

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