The spectrum of background radiation in the interstellar medium

Introduction. In 1994, I presented a composite background radiation field from radio frequencies to the H I Lyman limit in the far ultraviolet (Black 1994). This was done in the context of an assessment of energy budgets in diffuse molecular clouds. These notes provide a fuller description of how the radiation spectrum was constructed. An outline of further work in progress is also presented.

Components of the background radiation.

(1) Wright et al. (1991) proposed a simple power law to represent the non-thermal Galactic radio continuum

$$I'_\nu = 1.767 \times 10^{-19} \tilde{\nu}^{-0.75} \quad \text{erg s}^{-1}\ \text{cm}^{-2}\ \text{Hz}^{-1}\ \text{sr}^{-1} \tag{1}$$

where

$$\tilde{\nu} = \nu/c$$

is the wavenumber of the radiation in cm^{-1}.

(2) Wright et al. (1991) compared several analytical representations of the submm and far-IR radiation measured by COBE. I have adopted the simplest of these, a component of optically thin, thermal emission by warm dust at a single temperature

$$I'_\nu = 5.846 \times 10^{-7} \tilde{\nu}^{-1.65} B_\nu(T = 23.3\ \text{K}) \quad \text{erg s}^{-1}\ \text{cm}^{-2}\ \text{Hz}^{-1}\ \text{sr}^{-1} \tag{2}$$

where B_ν is the Planck function at a temperature of $T = 23.3$ K.

It is important to note that both of the above intensities refer to a map over the full sky that has a directional response function with an integrated solid angle of 3.8 sr. This integrated spatial function is a fraction 0.30 of 4π sr. Therefore, I adopted a mean intensity averaged over all directions

$$\langle I_\nu \rangle = 0.30 I'_\nu \tag{3}$$

based on the COBE model intensities of Wright et al. (1991).

(3) The cosmic background radiation (CBR) must be included, with

$$\langle I_\nu \rangle = B_\nu(T = 2.728\ \text{K}) \tag{4}$$

My original discussion used the preliminary COBE value of the CBR radiation temperature, $T_{\text{CBR}} = 2.732$, but I now recommend using the refined result $T_{\text{CBR}} = 2.728 \pm .004$ K based on the final analysis of COBE/FIRAS measurements (Fixsen et al. 1996).

I follow Wright et al. (1991) in extrapolating through the far-infrared ($\lambda = 25$ to $100\ \mu$m) according to the spectral shapes of normal spiral galaxies of the Virgo cluster as in Stark et al. (1989). The matching frequency has been adjusted until both the intensity and its first derivative with respect to frequency agree at $\tilde{\nu}_0 = 104.908$ cm^{-1}, where equation (2) is continued by

$$\langle I_\nu \rangle = 1.3853 \times 10^{-12} \tilde{\nu}^{-1.8381} \quad \text{erg s}^{-1} \text{ cm}^{-2} \text{ Hz}^{-1} \text{ sr}^{-1} \tag{5}$$

to higher frequencies. This expression is matched, in turn, with the mid-infrared spectra of Mathis et al. (1983) at 1113.126 cm^{-1}. At frequencies between 1113.126 and 4461.40 cm^{-1}, a polynomial fit

$$\langle I_\nu \rangle = 10^{-18} \Big[18.213601 - 0.023017717\tilde{\nu} + 1.1029705 \times 10^{-5} \tilde{\nu}^2 - 2.1887383 \times 10^{-9} \tilde{\nu}^3$$

$$+1.5728533 \times 10^{-13} \tilde{\nu}^4 \Big] \quad \text{erg s}^{-1} \text{ cm}^{-2} \text{ Hz}^{-1} \text{ sr}^{-1} \tag{6}$$

represents the intensity. At 4461.40 cm^{-1}, $\langle I_\nu \rangle = 3.01 \times 10^{-18}$ erg s^{-1} cm^{-2} Hz^{-1} sr^{-1}, and at higher frequencies, a piecewise polynomial fit to the solar-circle background intensity of Mathis et al. (1983) describes the spectrum from the near-infrared through the visible and ultraviolet regions to the H I Lyman limit, where the intensity vanishes.

The total integrated intensity of the above model of the background radiation is

$$4\pi \int \langle I_\nu \rangle d\nu = 0.053 \quad \text{erg s}^{-1} \text{ cm}^{-2} \tag{7}$$

where the integration extends from $\nu = 10^8$ Hz to the Lyman limit. The corresponding energy density is

$$u_\nu = \frac{4\pi}{c} \int \langle I_\nu \rangle d\nu = 1.10 \quad \text{eV cm}^{-3}. \tag{8}$$

Future work. The model of the submm and far-infrared background describes the broad-band continuous radiation only. There are several strong emission lines that contain significant flux in this part of the spectrum (see, for example, Fixsen, Bennett, & Mather 1999). The intensities of the stronger lines need to be taken into account.

The intensity of ultraviolet radiation is very sensitive to the distribution of O and B type stars as well as to local variations in extinction. There now exist large catalogues of known early-type stars in our part of the Galaxy. There also now exist dynamical models of hot stellar atmospheres, which are thought to offer a better representation of the ionizing radiation produced in hot stars. A student project will be carried out to construct a new model of the background radiation in the far-ultraviolet based on stellar catalogues and current model atmospheres. Similarly, the contribution of hot white dwarf stars to the diffuse ultraviolet radiation will be re-examined based on more extensive catalogues of white dwarfs that now exist.

References

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