-92-124

COBE-PREPRINT-No-92-124

4

Fermilab Library
0 1160 0020183 4

LARGE-SCALE PHYSICAL CONDITIONS IN THE INTERSTELLAR MEDIUM FROM DIRBE OBSERVATIONS

T.J. Sodroski[1], M.G. Hauser[2], E. Dwek[3], T. Kelsall[3], S.H. Moseley[3], R.F. Silverberg[3], N. Boggess[3], N. Odegard[4], J.L. Weiland[4], and B. Franz[1]

[1]Applied Research Corporation, Code 685.3, NASA/Goddard Space Flight Center, Greenbelt, MD 20771
[2]Code 680, NASA/Goddard Space Flight Center, Greenbelt, MD 20771
[3]Code 685, NASA/Goddard Space Flight Center, Greenbelt, MD 20771
[4]General Sciences Corporation, Code 685.3, NASA/Goddard Space Flight Center, Greenbelt, MD 20771

ABSTRACT

Observations from the COBE Diffuse Infrared Background Experiment (DIRBE) of the 140 and 240 μm emission from the Galactic plane region ($|b| < 10°$) are analyzed. Assuming an isothermal dust distribution along each line of sight, maps of dust temperature, optical depth, and total far-infrared (FIR) brightness are derived. These quantities are combined with available ^{12}CO and HI data to produce maps of the gas-to-dust mass ratio and the FIR luminosity per hydrogen mass. The results differ from those of a similar analysis using IRAS 60 and 100 μm data (Sodroski et al. 1987), at least in part because emission from small, transiently heated grains does not contribute significantly at 140 or 240 μm.

A linear correlation analysis is used to decompose the 140 and 240 μm maps into components associated with the neutral atomic (HI), molecular (H_2), and extended low-density ionized (HII) gas phases of the interstellar medium. From the resulting emission components the large-scale physical conditions within each gas phase are derived. The implications of the results for the current picture of the Galactic large-scale FIR emission are discussed.

EJ

1. INTRODUCTION

The close agreement of the results of several independent IRAS studies of the Galactic large-scale 60 and 100 μm emission (Sodroski et al. 1986, 1987, 1989; Perault et al. 1989; Bloemen, Deul, & Thaddeus 1990; and references therein) has placed tight constraints on the large-scale physical conditions within the most massive gas phases (HI, H_2, and HII) of the interstellar medium and the distribution of FIR luminosity among these gas phase components. However, the limitations of these studies include the following: (1) IRAS may not be sensitive to a cold dust component which consitutes a large fraction of the total dust mass in the ISM. (2) There may be a significant contribution to the emission at 60 μm from small, transiently heated grains. Analysis of DIRBE observations at 140 and 240 μm can be combined with the results of the IRAS studies to arrive at a more complete interpretation of the Galactic large-scale FIR emission.

C92/10/12.1

2. DATA SETS

The data used in this analysis comprise: (1) DIRBE (Hauser 1993) 140 and 240 μm observations at 0.7° resolution, from data averaged over 10 months of cryogenic operation. Zodiacal emission has not been subtracted. It is estimated to be less than 10% of the observed 140 μm intensity and less than 5% of the observed 240 μm intensity for all pixels along the Galactic plane (b = 0°); (2) Velocity-integrated HI 21-cm line observations at ~ 0.7° resolution. The data are from the surveys of Weaver & Williams (1973), Kerr et al. (1986), and Burton & Liszt (1983); (3) Velocity-integrated ^{12}CO ($J = 1 \rightarrow 0$) line observations at 0.5° resolution. The data are from the surveys of the Goddard Institute for Space Studies (Dame et al. 1987); (4) 5 GHz radio-continuum observations of the Galactic plane region from the survey of Haynes, Caswell & Simons (1978). The data were smoothed to ~ 0.5° resolution.

3. DERIVED PHYSICAL CONDITIONS ASSUMING A SINGLE DUST TEMPERATURE ALONG EACH LINE OF SIGHT

Galactic plane region ($|b| < 10°$) maps of dust temperature, optical depth at 240 μm, and total integrated brightness over all FIR wavelengths ($\lambda > 40$ μm) were derived by assuming that the dust distribution along each line of sight is isothermal, and has a λ^{-2} emissivity law (see Sodroski et al. (1987) for details of this type of analysis). A map of the total H atom column density was derived from the HI and ^{12}CO surveys. These maps were then combined to derive maps of the gas-to-dust mass ratio and FIR luminosity per hydrogen mass. In order to derive the gas-to-dust mass ratio map, a dust mass absorption coefficient of 7.2 cm^2 g^{-1} at 240 μm was assumed (Hauser et al. 1984).

The 240 μm optical depth map has a maximum value of ~ 0.02. This shows that, averaged over the 0.7° DIRBE beam, the Galaxy is optically thin at wavelengths ≥ 140 μm. The total FIR brightness at b = 0° decreases by almost an order of magnitude from the inner ($270° < \ell < 90°$) to the outer ($90° < \ell < 270°$) Galaxy.

Longitude profiles of the dust temperature, gas-to-dust mass ratio, and FIR luminosity per hydrogen mass at b = 0° were derived. The profiles represent the mean properties within the latitude interval $|b| < 0.75°$. The dust temperature has a mean value over all longitudes of ~ 19 K, and decreases by ~ 20% from the inner to the outer Galaxy. We have also derived the latitude distribution of dust temperature from data averaged over 12 longitude bins. The latitude distribution of dust temperature shows a general trend of decreasing temperature with increasing latitude for the inner Galaxy, and increasing temperature with increasing latitude for the outer Galaxy. These results suggest that the dust temperature in the Galactic disk decreases significantly with increasing galactocentric distance. Assuming an axisymmetric disk, the radial distribution of dust temperature in the Galactic disk has been estimated by unfolding the 140 and 240 μm longitude profiles. A dust temperature exponential scale length of ~ 20 kpc is obtained.

The gas-to-dust mass ratio profile has a mean value of ~ 160, a value consistent within the uncertainties with the local canonical value of ~ 100. The ratio increases by ~ 35% from the inner to the outer Galaxy. However, this derived increase may not be real, since the assumption of a single dust temperature along each line of sight may

lead to large errors in derived dust mass column density. The FIR luminosity per hydrogen mass has a mean value in the inner Galaxy of ~ 3 $L_\odot M_\odot^{-1}$, and decreases by a factor of ~ 4 from the inner to the outer Galaxy.

Within a few degrees of longitude of the Galactic Center, the gas-to-dust mass ratio reverses its general trend and increases by a factor of ~ 2 - 3 above the inner Galaxy value. The FIR luminosity per hydrogen mass also reverses its general trend and decreases by a similar factor below the inner Galaxy value. One possible explanation of these results is that there is a significant deficiency of dust in the central region of the Galaxy (galactocentric distance < 500 pc) relative to the Galactic disk. Another possible explanation is that the ratio of H_2 column density to ^{12}CO intensity is significantly lower in the central region of the Galaxy than in the Galactic disk (Blitz et al. 1985), in which case the column density of molecular gas along lines of sight near the Galactic center has been overestimated.

The derived dust temperature and FIR luminosity per hydrogen mass profiles have important implications for our current picture of the Galactic large-scale FIR emission. They suggest that the equilibrium temperature of large dust grains in the interstellar medium, and therefore the ambient radiation field which heats these grains, decrease rapidly with increasing galactocentric distance. However, the mean dust temperature and FIR luminosity per hydrogen mass of star forming regions do not vary significantly from the inner to the outer Galaxy (Wouterloot, Brand, & Henkel 1988; Mead, Kutner, & Evans 1990). Therefore, our results suggest that the primary heating source of the dust in the Galactic disk is the general interstellar radiation field (Sodroski et al. 1989), which decreases by almost an order of magnitude from a galactocentric distance of 5 kpc to the solar circle (Cox, Krugel, & Mezger 1986). The derived longitudinal variations of dust temperature and FIR luminosity per hydrogen mass are consistent, within the uncertainties, with the corresponding variations predicted for dust heated by the general interstellar radiation field.

4. THE LARGE-SCALE PHYSICAL CONDITIONS WITHIN THE INDIVIDUAL GAS PHASES OF THE ISM: LINEAR DECOMPOSITION OF THE 140 AND 240 μm DATA

The large-scale physical conditions within the three most massive gas phases (H_2, HI, and HII) of the ISM have been inferred by applying the linear decomposition method of Sodroski et al. (1989) to the 140 and 240 μm data within the region $300° < \ell < 40°$, $|b| < 1.25°$. For the HI gas phase, the derived dust temperature and FIR luminosity per hydrogen mass profiles each decrease with increasing longitude in a manner consistent with that expected for dust heated by the general interstellar radiation field. A comparison of these results with the results of a similar analysis of the IRAS 60 and 100 μm data (Sodroski et al. 1989) shows that the relative contribution to the FIR intensity increases with increasing wavelength for the molecular component, whereas that of the ionized component decreases with increasing wavelength, consistent with the generally accepted view that dust associated with ionized gas has a higher equilibrium temperature than dust associated with molecular gas. The FIR luminosity per hydrogen mass profiles for the HI gas phase from the two decompositions are in close agreement. However, the dust temperature profile for the HI gas phase from the

IRAS decomposition shows no significant variation with longitude. We conclude that this derived constancy in dust temperature is probably a result of the contribution from small (< 10 Å), transiently heated grains to the 60 μm intensity, as suggested by Sodroski et al. (1987, 1989).

It is inferred from this analysis that the total FIR luminosity of the Galactic disk is ~ 1.5 x 10^{10} $L_{\odot}$, with 70%, 20%, and 10% from dust associated with neutral atomic hydrogen clouds, molecular clouds, and extended low-density HII regions, respectively. This result is consistent with the results of the IRAS analyses of the Galactic plane (Sodroski et al. 1986, 1987, 1989; Bloemen, Deul, & Thaddeus 1990; and references therein).

For future work it is intended to incorporate the kinematical information of the ^{12}CO and HI surveys into the analysis in order to derive the distributions of the large-scale physical conditions with galactocentric distance, and to do a more detailed study of the physical conditions within the central region of the Galaxy.

ACKNOWLEDGEMENTS

COBE is supported by NASA's Astrophysics Division. Goddard Space Flight Center (GSFC), under the scientific guidance of the COBE Science Working Group, is responsible for the development and operation of COBE.

REFERENCES

Blitz, L., Bloemen, J. B. G. M., Hermsen, W., & Bania, T. M. 1985, A&A, 143, 267
Bloemen, J. B. G. M., Deul. E. R., & Thaddeus, P. 1990, A&A, 233, 437
Burton, W. B., & Liszt, H. S. 1983, A&AS, 52, 63
Cox, P., Krugel, E., & Mezger, P. G. 1986, A&A, 155, 380
Dame, T. M., et al. 1987, ApJ, 322, 706
Hauser, M. G. 1993, this volume
Hauser, M. G., et al. 1984, ApJ, 285, 74
Haynes, R. F., Caswell, J. L., & Simons, L. V. S. 1978, Australia J. Phys., Ap. Suppl., 45, 1
Kerr, F. J., Bowers, P. F., Jackson, P. D., & Kerr, M. 1986, A&AS, 66, 373
Mead, K. N., Kutner, M. L., & Evans, N. J. 1990, ApJ, 354, 492
Pérault, M., Boulanger, F., Puget, J. L., & Falgarone, E. 1989, ApJ, submitted
Sodroski, T. J., Dwek, E., Hauser, M. G., & Kerr, F. J. 1986, in Star Formation in Galaxies, ed. C. J. Persson (Washington, DC: US Government Printing Office), p.99
----------. 1987, ApJ, 322, 101
----------. 1989, ApJ, 336, 762
Weaver, H., & Williams, D. R. W. 1973, A&AS, 8, 1.
Wouterloot, J. G. A., Brand, J., & Henkel, C. 1988, A&A, 191, 323