Letter to the Editor

Stars in the bulge of our galaxy detected by IRAS

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ABSTRACT

A clear bulge is seen near the center of the Galaxy in the distribution of point-like sources discovered in the IRAS all sky survey at 12 and 25 μm. The IRAS bulge has a characteristic radius of 5° and contains more than 2500 stars with flux densities greater than 1 Jy at 12 μm. The sources have typical infrared luminosities of about 2,000 L☉ and 12-25 μm color temperatures between 250 and 450 K indicating they are dust embedded stars. Their colors are consistent with the sources being evolved late type M stars near the tip of the red giant branch.

Key words: Galaxy (the); bulge of, Infrared radiation, Galaxy (the); evolution of, Stars: circumstellar matter, Stars: OH/IR

I. INTRODUCTION

One of the conspicuous features in the all-sky maps produced from the unbiased infrared survey made by IRAS is the presence of a clear Galactic bulge seen in the distribution of point-like sources detected at 12 and 25 μm. Although the extent of the Galactic bulge has been observed at 24 μm in a balloon experiment by Maibara et al. (1976), most previous studies of the bulge have been restricted to observations in "windows," e.g., Baade (1948), in the Galactic extinction. Maibara et al. concluded the bulge was made up of a large number of late type giants. Large numbers of K giants (Whitford and Rich, 1983), some with high metallicity, and M giants (Blanco, McCarthy, and Blanco, 1984) have been identified in Baade’s window.

In this Letter we give a preliminary description of the bulge as seen by IRAS and discuss some features of its composition. The intent is to encourage follow up observations and analysis. A more detailed analysis of the IRAS observations is in progress.

II. OBSERVATIONS

The distribution of all sources found in the IRAS survey whose flux density at 12 μm exceeds that at 25 μm, shows a pronounced bulge near the Galactic center: a description of this distribution and of the IRAS mission is given in the IRAS Explanatory Supplement (1985). In order to better delineate the bulge, a comparison was made of the sources in two areas of the sky, each of which encompassed 400 sq deg. One area, 20 × 20°, was centered on the Galactic equator at Galactic longitude l = 20° and was used to define the disk population. A second 20 × 20° area was centered on the Galactic center and was assumed to contain both disk and bulge stars. The number of disk stars in this sample was assumed to be equal to that in the first area, while the difference was assumed to represent the bulge population.

Histograms for the two areas showing the number distributions of sources versus (a) the flux density f(12) at 12 μm and versus (b) the ratio f(12)/f(25) are given in Figure 1. It is

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seen that sources with:

\[ 1 < \nu f(12) < 5 \text{ Jy} \]
\[ 0.5 < \nu f(12)/f(L_\odot) < 1.5 \]  

(1)
define a population which is prominent in the bulge region compared to the disk; these criteria were used to select the source shown in Figure 2. Only sources which have high and moderate quality flux density measurements at 12 and at 25 \( \mu m \) were included in the figure; for a definition of “quality” see the IRAS Explanatory Supplement (1985). No correction was made to the flux densities for the finite band widths used with the IRAS detectors. Note that these criteria define the bulge in the IRAS point source data base and do not necessarily reflect the intrinsic properties of the bulge stars. In particular, the cutoff of 1 Jy could be caused entirely by the IRAS catalog itself.

III. CHARACTERISTICS OF THE BULGE AND BULGE SOURCES

The total number of stars which obey the criteria of Eqn (1) and are located within the central 20 \( \times \) 20° area of the Galaxy is 4,865 while that in the adjoining 20 \( \times \) 20° area to the east of the center is 2,315. Thus, if the same disk population is present in both regions, statistically the total number of “bulge” stars in Figure 2 is 2,568. For comparison, the total number of stars in the IRAS point source catalog obeying the criteria of Eqn (1) and lying outside the region with Galactic latitude \( |b| < 2° \) is 5072.

One half the sources obeying Eqn (1) and lying within a radius of 10° from the Galactic center, but at radii larger than 2°, are within a radius of 5°. If the center of the Galaxy is at a distance of 8.5 kpc, this corresponds to a projected radius of \( \sim 750 \) pc. If circular annuies of width 0.25° are projected against the bulge, and the region with Galactic latitudes \( |b| < 2° \) is omitted, the projected surface density of sources obeying the criteria of Eqn (1) follows a relation similar to those found for external galaxies by de Vaucouleurs (1974) - see Figure 3. Because the de Vaucouleurs relation lacks a dynamical explanation it is difficult to evaluate the significance of the relation in Figure 3.

From Figure 1 it is seen that the mean 12 \( \mu m \) flux density of the sources defining the bulge through Eqn (1) is \( \sim 2.3 \text{ Jy} \) corresponding to a total flux density from the 2,568 bulge sources of \( f(12) = 5,900 \text{ Jy} \). The total bolometric luminosity \( L_\text{bol} \) of these sources can be estimated by:

\[ L_\text{bol} = (1.5 \nu f(12)) \times 4 \pi D^2 \]  

(2)

where \( \nu \) is the frequency \( 2.5 \times 10^{18} \text{ Hz} \), corresponding to a wavelength of 12 \( \mu m \). The factor 1.5 is a lower limit: if a black body curve is drawn through the flux density at 12 \( \mu m \), then \( F_\text{tot} > 1.5 \nu \times f(12) \text{ (12}\mu m) \), where \( F_\text{tot} \) is the flux density integrated over all frequencies. If the center of the Galaxy is at \( D = 8.5 \) kpc and the total flux density is 5900 Jy, the bolometric luminosity is \( L_\text{bol} = 4.9 \times 10^5 L_\odot \). If, as indicated below, the energy distribution is that of black body radiation at a temperature between 250 and 450 K, Eqn (2) provides an estimate within 50% of the total luminosity of the source. The estimate is furthermore reasonable if the continua of the stars in the bulge resemble those identified with IR/OH stars (Olson et al., 1983). As a comparison, Soifer et al. (1985) find that the bolometric luminosity of excess emission from the bulge in M31 is \( 1.2 \times 10^7 L_\odot \).

The plot of the 12 to 25 \( \mu m \) flux density ratio versus the 25 to 60 \( \mu m \) flux density ratio of sources which obey the criteria of Eqn (1) is shown in Figure 4. Only sources which were detected at 60 \( \mu m \) which had Galactic latitude \( |b| < 10° \) and longitude \( 1° < 10° \) are included. The track of late M stars (Olson et al. 1983) are included in Figure 4 as is the blackbody emitter track. It is clear that a significant fraction of the bulge stars have the same 12 to 25 \( \mu m \) and 25 to 60 \( \mu m \) colors as the late type oxygen rich M stars. In contrast, a comparison with a similar plot by Hacking et al. (1980) indicates that there is not a significant population of carbon stars in the bulge. This is consistent with the work by Blanco et al. (1984) who found no carbon stars in Baade’s window.

![Figure 2](image)

**Figure 2.** The distribution of sources in the sky with flux densities at 12 \( \mu m \), \( f(12) \), satisfying \( 1 < f(12) < 5 \text{ Jy} \) and \( 0.5 < f(12)/f(L_\odot) < 1.5 \). The grid is plotted in Galactic coordinates in an Altolf projection and the Galactic center is in the middle of the picture.

![Figure 3](image)

**Figure 3** The normalized surface density \( 1/f_\odot \) in annular rings of width 0.25° in a function of \( (r/r_\odot)^{-1} \), where \( r/\text{re} \) is the normalized radius. Sources with Galactic latitude \( s|b| < 2.0° \) are omitted. The effective radius \( r_\odot \) is chosen as 5.0° corresponding to a surface density \( f_\odot = 15.7 \text{ sources/(sq deg)} \). The quality of the fit is not sensitive to the choice of \( r_\odot \). The dashed line corresponds to the relation found by de Vaucouleurs (1974) in external galaxies. An equally good fit is found when the annular rings are elliptical instead of circular.
The sources as defined by the criteria in Eqn (1) were examined for variability, which, because of the scanning pattern of the IRAS survey, most likely had to occur on a 6 month time scale. It was found that of the bulge population, 25% had a "probability of variability" exceeding 0.99 (IRAS Explanatory Supplement 1985), corresponding to a relative flux change at 12 and 25 μm exceeding 40%. For comparison, 13% of all stars examined for variability had a "probability of variability" greater than 0.99; the difference is significant.

IV. THE NATURE OF THE BULGE SOURCES

The nature of the sources making up the IRAS bulge population is uncertain, and the IRAS observations are not sufficient to specify the sources uniquely. Only about 2% are positionally associated with visually identified sources. These 2% divide about evenly between known variable stars (long period variables) and planetary nebulae. Some planetary nebulae have high radial velocities, giving independent proof that they are part of the galactic bulge.

From Eqn (2) the bolometric luminosity of an individual bulge source at a distance of 8.5 kpc and with a flux density of 2.3 Jy is 1,850 L₀. This luminosity, corresponding to an absolute bolometric magnitude of Mₖ = -3.5 mag, is suggestive of stars near the tip of the red giant branch. Although this identification is not unique, it is consistent with preconceived notions of stellar evolution and the formation of the bulge at the time the Galaxy was formed. This identification is also consistent with the presence of a large number of red giants in the bulge inferred from observations in Baade's window (Wood and Bessell, 1983; Blanco, McCarthy and Blanco, 1984; Fugel, Whifford and Rich, 1984). The high percentage of variability found on a 6 month time scale in the bulge stars is also consistent with this interpretation. It is quite possible that a significant fraction of the bulge stars is brighter than Mᵦ ≈ -3.5 mag. There may be significant luminosity at the shorter wavelengths which is not accounted for in Eqn (2) and 2.3 Jy is only a median value for the 12 μm flux density. Progol (1981) has reported the presence in the Galactic bulge of M giants more luminous than those found in globular clusters. It is of importance to know how many of the IRAS sources are similarly luminous.

The 12 to 25 μm color temperatures Tₓ of the bulge stars occupy the range 250 < Tₓ < 500 K. These low temperatures are not characteristic of the photospheric temperatures of the stars, but rather indicate the presence of substantial dust shells surrounding the stars. The photospheric emission of a 3,000 K star located at the Galactic center with a luminosity L = 1,800 L₀ corresponds to a 12 μm flux density at the Earth of 0.2 Jy. Thus the 12 μm emission in the bulge is dominated by emission from circumstellar dust. By analogy with other stars showing excesses in similar colors, e.g., extreme Mira variables and the OH/IR stars, it can be conjectured that the dust shells have significant optical depth.

If radiation pressure on grains is responsible for most of the mass loss from bulge stars, then the mass loss can be approximated by (Salpeter, 1974; Werner et al. 1980):

\[
\frac{dM}{dt} = \frac{\tau_d \times L_d}{(c \times V_d)}
\]

where \(\tau_d\) is the optical depth in dust at optical wavelengths, \(L_d\) is the stellar luminosity and \(V_d\) is the expansion velocity of the circumstellar shell. If the optical depth is large or the grains have low albedo at optical wavelengths, then \(\tau_d \times L_d \sim L_d\) and \(dM/dt \sim L_d/(c \times V_d)\). If this approximation is combined with the earlier estimate of Lₜ₀ for the bulge stars,

\[
\frac{dM}{dt}(\text{mean object}) \sim 3.5 \times 10^{-9} \left(\frac{V_d}{15 \text{ km sec}^{-1}}\right) M_\odot \text{ yr}^{-1}
\]

and

\[
\frac{dM}{dt}(\text{bulge}) \sim 0.9 \times 10^{-6} \left(\frac{V_d}{15 \text{ km sec}^{-1}}\right) M_\odot \text{ yr}^{-1}
\]

The estimate for the total mass loss rate for the IRAS bulge objects neglects any contribution by stars fainter than 1 Jy at 12 μm. Werner et al. (1980) have found that \(V_d \sim 15 \text{ km sec}^{-1}\) is a reasonable estimate of the expansion velocity for a sample of OH/IR stars. If, however, the bulge stars are super metal rich (Whifford and Rich, 1983) then \(V_d\) may be substantially higher with a corresponding decrease in \(dM/dt\).

It should be finally admitted that the IRAS observations cannot answer the important questions of the age and metal abundances of the stars making up the bulge. Are these stars young asymptotic giant branch stars or are they evolved from an old population with high metal abundances? Detailed observations of the individual stars making up the bulge are clearly necessary to answer these and related questions.

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