IRAS OBSERVATIONS OF THE GALACTIC CENTER

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Abstract. IRAS observations of the Galactic Center are presented. The maps at 12, 25, 60 and 100 μm have a typical resolution of a few arcmin and cover an area 6x2 deg^2 centered on SgrA. All data have been corrected for the zodiacal light contamination and for the diffuse emission associated with the galactic disk. The infrared radiation originating in the Galactic Center arises from well-defined sources which can be identified with known radio sources and from an extended emission which accounts for most of the infrared luminosity. The total infrared luminosity associated with the Galactic Center (area 3°x 2°) amounts to $10^9 L_\odot$. The sources contribute 10% to this luminosity. A comparison with surveys in the radio continuum and in the near infrared is presented. Results are analyzed in terms of star formation history. In particular, it is suggested that the dominant heating source for the dust is the population of cool stars - K and M giants - comprising the galactic nucleus.

1. Introduction

Almost all of the ultraviolet and visible stellar luminosity emitted by the Galactic Center is absorbed by interstellar grains and reradiated in the infrared. If infrared data are available at several wavelengths, then information can be derived on the distribution of dust temperature, on the column density of dust and the distribution and nature of the sources that heat the dust.

Observations of the Galactic Center have in the past focused on the inner few parsecs (see Brown and Liszt, 1984 for a comprehensive review) and comparatively little work has been done on the structure of the Galactic Center between radii of 3 and 250 pc. Most of the infrared data published to date follows this trend and large scale far-infrared surveys for the Galactic Center are sparse. Made by balloon (Stier et al., 1982; Odenwald and Fazio, 1984), these large scale surveys experiments suffer either from an inevitable underestimate of the diffuse infrared emission due to specific chopping and scanning techniques, or from low resolution. These problems have only been solved with the Infrared Astronomical Satellite (IRAS) observations, and only when detectors with DC coupled preamplifiers were used so that the total power intensities could be measured.

The following pages report on a detailed analysis of the IRAS measurements related to the interstellar environment of the Galactic Nucleus. Maps have been constructed of the *intrinsic* Galactic Center infrared emission on the basis of the IRAS sky surveys at full resolution. Morphological studies, relationships between molecular and atomic constituents and the infrared emission, investigations of the physical conditions (dust temperature, luminosity and mass) and the nature of the heating sources, especially in regions far from the well-studied central few arc minutes, are presented.

M. Morris (ed.), The Center of the Galaxy, 121–128.
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https://doi.org/10.1017/S0074180900186401 Published online by Cambridge University Press

2. Results

Figures 1a - d show the contour maps of the *intrinsic* infrared surface brightness of the Galactic Center in the four IRAS bands at 12, 25, 60 and 100 μm, respectively. The contributions of the zodiacal emission and of the diffuse infrared emission associated with the galactic disk have been removed, as described in Cox and Laureijs (1988). The maps cover a 6° x 2° field centered on the Galactic Nucleus with a resolution of about 5 to 6 arcmin.

These maps reveal a highly-structured diffuse emission in the inner parts of the Galaxy as well as emission from prominent sources including the well-known objects SgrA, SgrB2, SgrC and Sgr D. At all four wavelengths, the spatial distribution of the infrared emission remains very similar to that of the radio continuum emission (see Fig.2). Practically all sources present in the infrared maps have counterparts in the radio surveys and every diffuse structure can be traced back in both the radio and the infrared data. The recently discussed Galactic Center Lobes (Sofue, 1985) at positive latitudes and at l=0° and 359°5 are clear entities at all four IRAS wavelengths and the well-defined structures protuding southward from the galactic plane at l=359°7 and 359°2 in the radio map are conspicuous in the IRAS data. However, for two sources, only clearly seen at 25 μm and located at l=-0°5, b=0°43 and l=-0°35, b=-0°26, no trace was found in any of the published radio surveys. A careful examination shows that the surface brightnesses of these sources are lower than or comparable to the far infrared and radio brightness associated with the radio lobes. Their spectral properties are characteristic of HII regions, although these sources are exceptional for both their high dust temperature (~70 K) and extension (~30 arcmin). A direct association with the Galactic Center has still to be confirmed.

A remarkable characteristic of these large scale views of the Galactic Center Region is the relative isolation of the nucleus. It can in fact be treated as a separate, well-defined source. Its extent is about ~3°x2°, corresponding to 450x300 pc^2 for an assumed distance $R_{\odot}$ =8.5 kpc.

3. Infrared Properties

3.a Global Properties

Combining all the information available to date on the 3°x2° region around the Galactic Center yields the spectrum presented in Figure 3. References are given in the figure caption. This composite spectrum from 2μm to 75 cm includes both the diffuse component and the sources. Most of the luminosity resides in the far infrared, the flux density peaking at about 100 μm. The infrared and submillimeter data are consistent with an averaged dust temperature of 27 K, assuming a λ^{-2} emissivity law for the dust. The emission of the old stellar population dominates at near infared wavelengths. The radio part is a mixture of thermal/non-thermal emission, with about equal contributions at 5 GHz (see below). The bolometric corrected luminosity derived from this spectrum is equal to $10^9 L_{\odot}$. It is of interest to note that the total infrared and submillimeter flux can be approximated within 10% by the sum $\Sigma \nu I_{\nu}$ over the four IRAS bands (see also Pérault et al., 1988).

The total mass of gas associated with the Galactic Center can be estimated from the bolometric luminosity and the dust emission per H-atom given by

$$W_e^H = 1.44\ 10^{-31} (Z/Z_{\odot}) T_d^6 \quad \text{erg s}^{-1} \qquad (1)$$

where T_d represents the dust temperature and $Z/Z_{\odot}$ accounts for metallicity gradients (see Mezger et al., 1986). Comparison with the bolometric luminosity yields the number of hydrogen atoms

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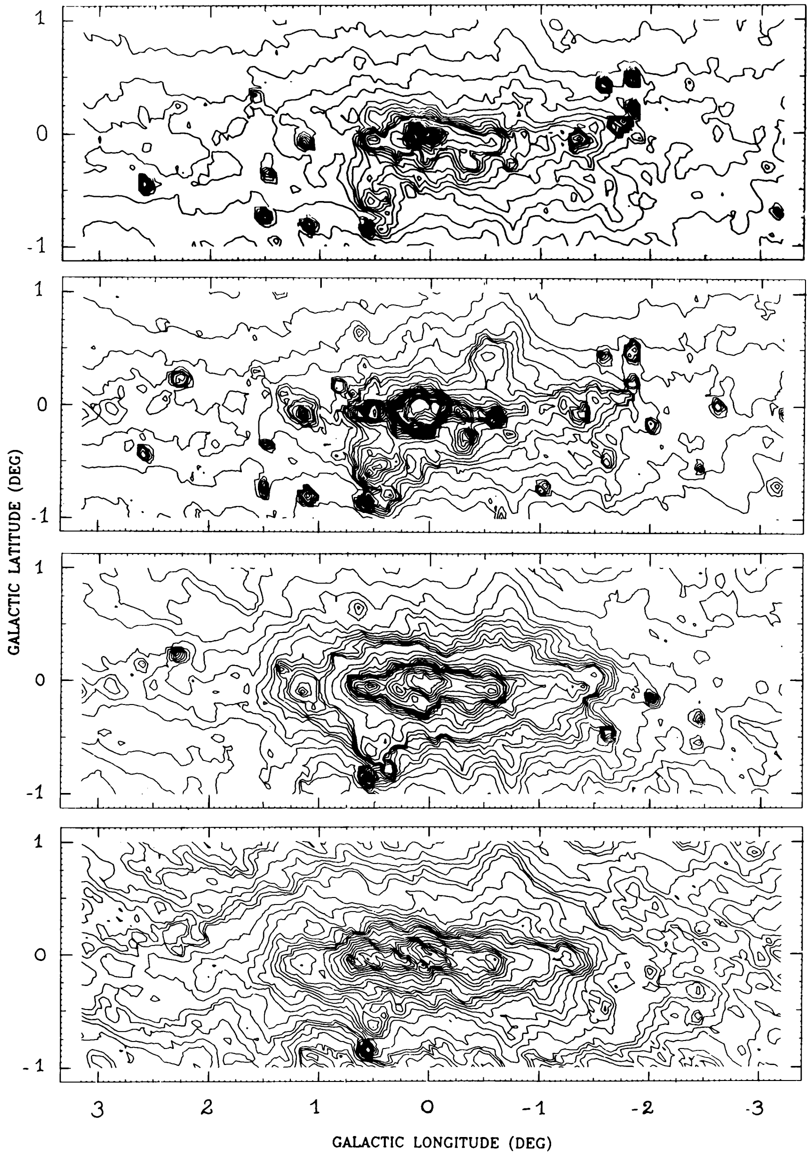

Figure 1 (a to d). Contour plots of the surface brightness distribution of the Galactic Center over a region 6°x3° at 12, 25, 60 and 100 μm, from top to bottom. The contours, in units of MJy sr^{-1}, are as follows: (a) 20 to 120 by steps of 10 (i.e 20:120:10), 125:575:25; (b) 5:75:10, 100:900:50, 1000:3000:1000; (c) 25, 50, 100:900:100, 1000:5000:500, 6000 and 8000; (d) 50:250:50, 400:1000:250, 1500:5000:500, 6000:24000:2000. The resolution is about 5-6 arcmin. The maps have been corrected for the zodiacal emission and for the diffuse emission associated with the galactic disk. Striping effects are clearly apparent at 100 μm: this defect is inherent to the actual IRAS data and is a result of the calibration process used (see Explanatory Supplement). The next generation of IRAS products will be corrected for this artifact.

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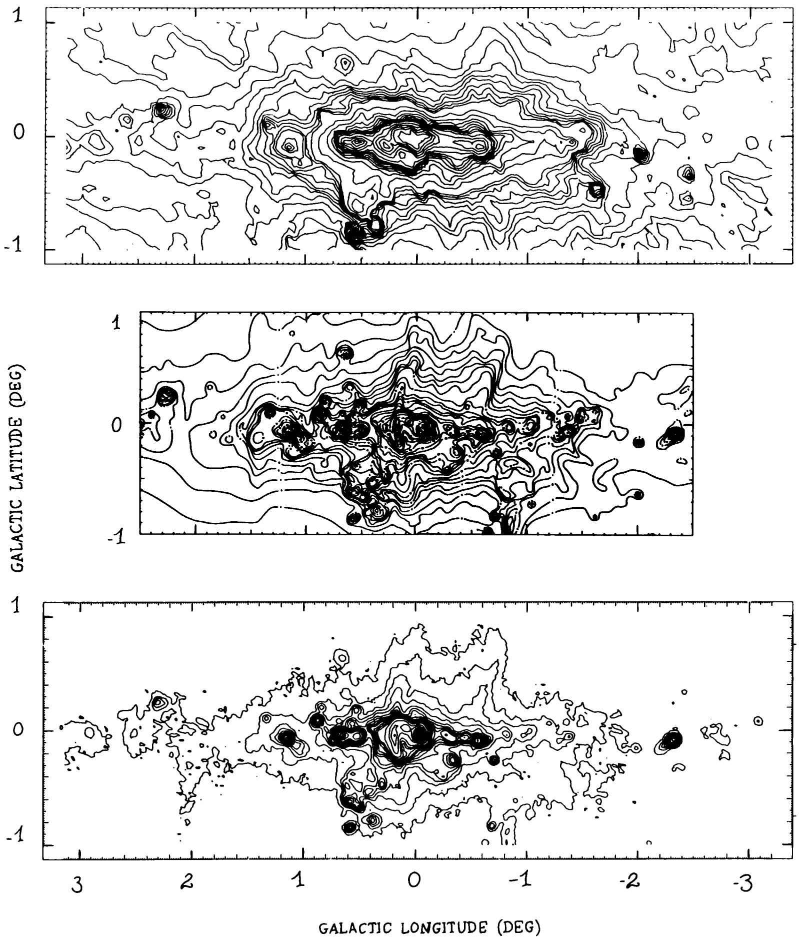

Figure 2. Comparison of the far infrared and radio continuum emissions associated with the Galactic Center Region. (top) 60 μm dust emission, as in Fig. 1c, (middle) 6 cm continuum emission (Altenhoff et al., 1978) and (bottom) 3 cm continuum emission (Handa et al., 1987) both with a 2'6 resolution.

and hence the gas mass after correction for Helium. From $T_d = 27$ K and $Z/Z_\odot = 2$ (extrapolated from the heavy element abundance in the galactic disk), we obtain for $L = 10^9 L_\odot$

$$M_{gas} = 3.6\ 10^7 M_\odot$$

within a 3°x2° area centered on the Galactic Nucleus. This estimate is in perfect agreement with the mass derived from the 890 μm flux (see Pajot et al., 1988).

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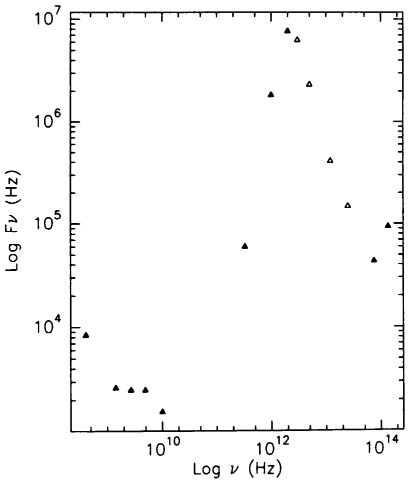

Figure 3. Spectrum of the Galactic Center region within an area Δl x Δb = 3°x2°, including both the sources and the diffuse component. The points at λ≤25 μm have been corrected for extinction. Open triangles are the IRAS observations. Spectral points at 150 and 300 μm are derived from Stier et al. (1982); the measurement at 890 μm is taken from Pajot et al. (1988). The 4 and 2.4 μm points are taken from Little and Price (1986) and Hayakawa et al. (1981), respectively. The radio measurements are derived from: Handa et al. (1987) for 10 GHz, Haynes et al. (1978) for 5 GHz, Reich et al. (1984, 1988) for 2.7 GHz and 1.4 Ghz, Haslam et al. (1980) for 408 MHz.

From the radio continuum data, one can estimate the contribution of the free-free emission to the total fluxes and hence derive the observed number of Lyman continuum photons. The importance of the Lyman continuum photons in the heating of the dust can be measured by the Infrared Excess (IRE) given by

$$IRE = 238\, L_{IR}(10^6) / N'_{Lyc}(10^{48})$$

where L_{IR} is the bolometric luminosity in units of $10^6 L_\odot$ and N'_{Lyc} is the observed number of Lyman continuum photons in units of $10^{48} s^{-1}$. If IRE= 1, the far infrared luminosity can be explained by stellar Lyman continuum photons which after absorption by the gas and degradation to Ly α are absorbed by dust. If IRE > 1, either direct dust absorption of stellar photons or additional stars producing little ionization (or both) are needed. The thermal contribution to the radio continuum fluxes at 5 and 10 GHz were estimated from the (non thermal) 408 MHz flux assuming a spectral index of $\nu^{-0.9}$ for the synchrotron radiation. The estimated free-free contributions at 5 and 10 GHz are 65 and 70 %, respectively.

Table I. Characteristics of the Galactic Center (3°x2°)

Size	450 x 300 pc^2	for $R_\odot$ = 8.5 kpc
Luminosity	$10^9 L_\odot$	bolometric corrected
Dust Temperature	27 K	
Gas Mass	3.6 $10^7 M_\odot$	30% uncertainty
Radio Flux (at 5 GHz)	2.5 10^3 Jy	65 % thermal contribution
N'_{Lyc}	10^{52} s^{-1}	observed Lyc photons*
Infrared Excess (IRE)	~30	for the diffuse emission

* sources contibute 20%

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We derive for most of the sources associated with the Galactic Center an average IRE of 10. This value is typical for galactic plane HII regions (see, e.g., Myers et al., 1986). The IRE of the diffuse component (estimated after correcting N'_{Lyc} for the source contribution, ~20%, as given by Mezger and Pauls, 1979) amounts to ~30, which is significantly in excess over the individual sources. Such a high value could imply that the extended emission is heated by a much later population of stars than for the discrete sources in the Galactic Center. These results are consistent with previous studies on the star formation in our Galaxy (Boissé et al., 1981; Odenwald and Fazio, 1984).The averaged properties of the 3°x2° area around the Galactic Center region are summarized in Table I.

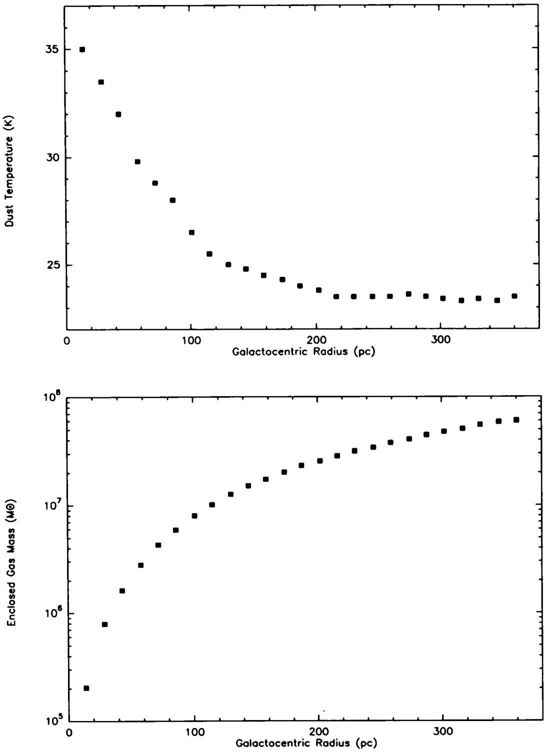

Figure 4. (a) Radial profile of the dust temperature, derived from the 60/100 μm brightness ratio assuming a λ^{-2} dust law.(b)Radial distribution of the gas mass associated with the Galactic Center. The mass is estimated as explained in the text.

3.b Radial Dependence of the Infrared Properties

In order to facilitate the derivation of the infrared properties associated with the Galactic Center, the IRAS surface brightness distributions have been integrated in ellipses. The ellipse parameters have been determined by fitting the lower contours of the IRAS maps. The center was taken at (l,b) = (0,0). The region is fitted with an ellipse of axial ratio 0.7, for a positional angle of 90°. Far from the inner few parsecs, these values are typical for the distribution of the old stellar population

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as derived from 2 μm observations (Matsumoto et al., 1982).

The dust temperature profile of the Galactic Center is shown in Fig. 4a and is derived from the 60/100 μm brightness ratio, assuming a λ^{-2} dust emissivity law. The dust temperature peaks at ~35 K and decreases as $r^{-0.3}$ until distances of 200 pc, where it attains a value of ~23 K, a characteristic temperature for dust heated by the interstellar radiation field.

The dependence of the gas mass on the distance to the Galactic Center is displayed in Fig. 4b. The masses have been estimated from the luminosities, derived by summing νI_ν over the four IRAS bands (see above) and the intensity weighted dust temperatures. The gas mass increases with distance as $r^{1.8}$, implying a constant surface density for the gas distribution, and attains a value of $6\,10^8 M_\odot$ within an area of 5°x3°5 (i.e. 750 x 520 pc^2). Since no submillimeter data are available to give a more accurate determination of the dust temperature over such extended areas some caution should be taken with regard to these numbers. The results are sensitive to the adopted dust temperature (eq. 1) and a 1 K uncertainty for T_d = 23 K results in a factor ~1.3 uncertainty in the mass. Numbers for the gas mass within regions bigger than 3°x2° should thus be regarded accurate to a 50% level. Comparison with estimation based on molecular data is discussed in detail by R. Güsten (this symposium).

The luminosity, computed from the sum of νI_ν in the four IRAS bands, is shown as a function of galactocentric distance in Fig.5. The luminosity increases by more than an order of magnitude in the inner 100 parsecs, varying from $6\,10^6 L_\odot$ within the central 10 pc to $2\,10^8 L_\odot$ at 40 pc. For distances greater than 100 pc, the luminosity increases smoothly towards $10^9 L_\odot$. The total far infrared emission associated with the Galactic Center is thus not in excess of $10^9 L_\odot$ and represents about 10% of the total galactic infrared luminosity (see Cox and Mezger, 1988). The discrete sources contribute only 10 % to this number.

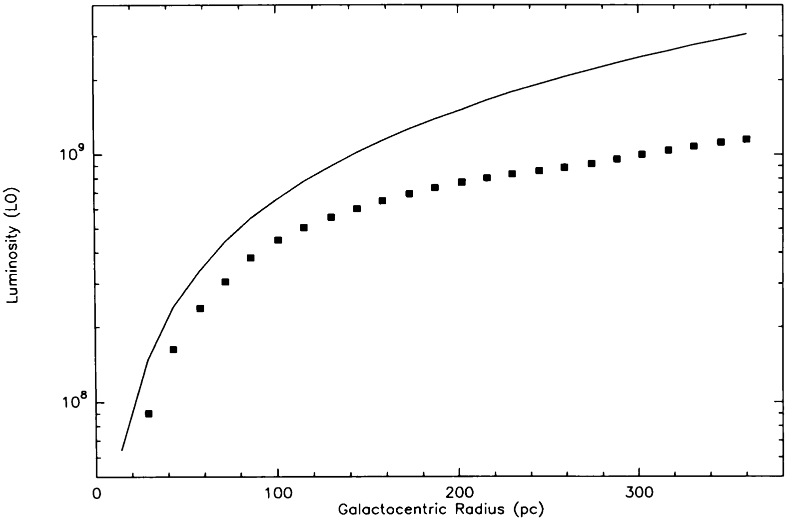

Figure 5. Radial distribution of the infrared luminosity associated with the Galactic Center as derived from the IRAS data (squares). The full line shows the total luminosity available from the old stellar population.

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The solid line shown in Fig. 5 represents the total luminosity available from the old stellar population in the Galactic Nucleus as derived by Sanders and Lowinger (1972) from the 2.2 μm observations by Becklin and Neugebauer (1968). Similar results are obtained from the larger scale 2.2 μm data of Matsumoto et al. (1982). The conversion of the observed surface brightness into luminosity has been performed after correction for the extinction and assuming that the spectral-energy distribution of the radiation from the stellar population is that of a 4000° K blackbody (which corresponds to a population of M and K giants). The luminosity available in the old stellar population is typically twice to three times higher than the infrared luminosity. This fact may suggest that most of the visible light of this old stellar population comprising the Galactic Nucleus is ultimately absorbed by the dust and reradiated in the infrared. This could then in turn account for the high value of the Infrared Excess (IRE ~30). These findings, however, do not exclude that, e.g., late B type stars, responsible for the low excitation found in the Galactic Center and the ionization of the diffuse gas, also participate in the heating of the dust. But they do not have to produce *all* of the heating. Detailed radiation transport calculations are currently under consideration to analyze this problem in more detail (Cox and Laureijs, 1988).

Acknowledgments: We would like to thank R. Güsten, R. Sanders and P. G. Mezger for useful discussions. P. Cox gratefully acknowledges the support of an Alexander von Humboldt Fellowship.

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