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INFRARED OBSERVATIONS OF THE GALACTIC CENTER. I. NATURE OF THE COMPACT SOURCES

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ABSTRACT

Photometry from 1.25 to 12 μm and spectrophotometry from 8 to 13 μm of the compact sources found in the galactic-center region are reported. In addition, revised 10 and new 20 μm maps with 2".3 resolution are given.

The nature of the compact sources is discussed. Some are best identified as stars or star clusters; the brightest source at 2 μm is probably a supergiant, and the infrared source near the nonthermal radio source is probably a stellar cluster with density greater than $10^6\ M_\odot\ \mathrm{pc}^{-3}$. Other sources emit most of their luminosity at wavelengths of 10 μm and greater; this emission is probably from heated dust. One of the sources is observationally similar to extremely red OH/infrared stars. Other sources have luminosities and linear sizes similar to those of compact H II regions; emission from optically thin silicate dust is seen in these.

Subject headings: galaxies: Milky Way — galaxies: nuclei — infrared: sources

I. INTRODUCTION

The galactic center is known as a bright source of 2–20 μm radiation (Becklin and Neugebauer 1968, 1969; Low *et al.* 1969). Maps with 2"–5" spatial resolution (Rieke and Low 1973, hereafter RL 73; Becklin and Neugebauer 1975, hereafter BN 75) have shown that, in a 40" diameter region, the radiation comes from at least 19 discrete sources as well as from an extended background. Several of the discrete sources have been shown to be stars (Neugebauer *et al.* 1976; Soifer, Russell, and Merrill 1976; Treffers *et al.* 1976), and most of the 2–3 μm radiation in the extended background is thought to be coming from stars (Becklin and Neugebauer 1968). Several discrete sources are seen best at 10 μm; the nature of these is uncertain, although some have properties similar to compact H II regions or planetary nebulae (RL 73; BN 75). The origin of the extended 10 and 20 μm radiation is also uncertain.

Three kinds of observations have been made to study the nature of the sources observed from 1 to 20 μm, both discrete and extended. First, a new 20 μm map of the region was obtained with 2".3 resolution; the 10 μm map with the same resolution was extended farther to the east; and independent positions were determined for the discrete 10 μm sources. Second, broad-band photometric observations from 1.2 to 12.5 μm were made of individual compact sources; the diaphragms used were small enough to separate the source being observed from other compact sources and from the extended background; 14 sources were observed in this manner, although not all were observed at all wavelengths. Third, spectrophotometric observations with 1% spectral resolution and 5" diaphragms were made from 8 to 13 μm at 8 positions; the primary results of the spectrophotometry are to confirm the strength and identification of silicate absorption observed with the broad-band filters and to measure the strength of the [Ne II] emission line at 12.8 μm as a function of position.

The results of the present study are given in four papers, divided by subject rather than type of observation. In this paper, the observations are used to determine the nature of the sources. In Paper II (Willner 1978), the observations of the [Ne II] line are used as an indicator of the distribution of ionized gas in the galactic center. Spectroscopy near 2.2 μm is used in Paper III (Neugebauer *et al.* 1978) to map the Bγ line. The interstellar extinction to the galactic center is discussed in Paper IV (Becklin *et al.* 1978).

II. OBSERVATIONS

A revised and extended version of the 10 μm map of BN 75 is presented in Figure 1. New data, consisting of scans to the east of IRS 1 with 2".3 resolution, were obtained on 1975 July 1 on the 5 m Hale telescope. The observation and reduction procedure was the same as that of BN 75. New relative positions of all the discrete 10 μm sources were also measured. The new positions have been incorporated into Figure 1; the most significant change is that IRS 3 is closer to IRS 7 than was indicated by BN 75. The absolute coordinates of the map were also remeasured, using the optical field star indicated by an X. The new positions shown in Figure 1 differ from those of BN 75 by 2" in the sense that the new positions are south of those given by BN 75. The difference is probably due to the difficulty of accounting for the effects of differential refraction. It should be noted that the present positions, although based on four independent measurements, including those of BN 75, still have an uncertainty of about $\pm 2''$ in both coordinates.

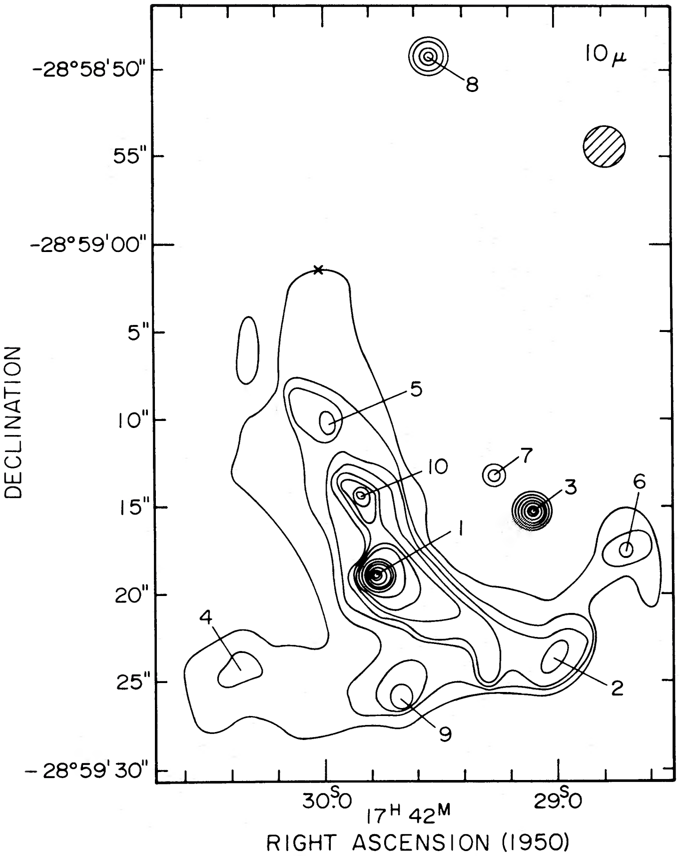

FIG. 1.—Map of the galactic-center region at 10 μm (Δλ = 5 μm) made with a 2″.3 circular diaphragm on the Hale 5 m telescope. The beam size is shown by the hatched circle in the upper right-hand corner. The X denotes a visible field star. The IRS numbers are shown. The contour interval is 4 × 10^{10} Jy sr^{-1} (4 Jy per beam). The portion of the map west of $17^h42^m30^s$ is from the data of BN 75, with recalibrated positions and brightnesses (see text).

A 20 μm (Δλ = 7 μm) map with 2″.3 resolution made in 1975 March on the 5 m Hale telescope is shown in Figure 2. The portion of the map east of $17^h42^m30^s.2$ is completed with 5″ resolution scans made on the Hooker 2.5 m telescope in 1972 June. The absolute flux is uncertain to a factor of 1.5 because of the large and poorly known atmospheric extinction at 20 μm.

Broad-band observations of individual locations were made at the 5 m Hale telescope on four nights in 1975 June and July, with the wavelength bands at 1.25 μm (Δλ = 0.3 μm), 1.65 μm (Δλ = 0.3 μm), 2.2 μm (Δλ = 0.4 μm), 3.5 μm (Δλ = 0.6 μm), 4.8 μm (Δλ = 0.6 μm), 8.7 μm (Δλ = 1.2 μm), 9.5 μm (Δλ = 1.5 μm), 10.1 μm (Δλ = 5 μm), 11.2 μm (Δλ = 1.5 μm), and 12.5 μm (Δλ = 1.3 μm). The absolute calibration is given by Beckwith *et al.* (1976).

The 1.25–4.8 μm observations were made with an InSb detector, either a 3″.8 or a 5″.0 diaphragm, and a focal plane chopper producing a 7″.5 beam separation in declination. The 8.7–12.5 μm observations used a bolometer detector, a 2″.3 diaphragm, and a wobbling secondary chopper producing a 10″ beam separation in declination. The visual seeing was better than 2″ for all of the observations. The position of each source to be measured was determined on the basis of the infrared signal of the individual objects at either 2.2 or 10 μm. The spatial resolution was similar to that employed by BN 75 to make the 2.2 and 10 μm maps of the galactic center.

All of the infrared observations presented in this paper have been corrected for interstellar extinction, as will be discussed in Paper IV. The extinction in the 1.2–3 μm region is derived from the assumption that the background flux comes from reddened giant and supergiant stars and agrees with curve 15 of van de Hulst (1946). The extinction curve near 10 μm is based on the observations of IRS 7 (see below) and the assumption that its energy distribution is smooth in that wavelength region. In particular, it is assumed that IRS 7, which has been identified as a late-type star (Treffers *et al.* 1976), has no strong intrinsic silicate emission or absorption near 9.5 μm. The derived extinction differs from that based on observations of VI Cyg No. 12 (Rieke 1974; Gillett *et al.* 1975*b*) in the sense that the galactic center shows twice as much silicate absorption for the same amount of 1–3 μm reddening. The corrections applied and the resultant magnitudes are given in Table 1.

The measured flux densities from the photometry

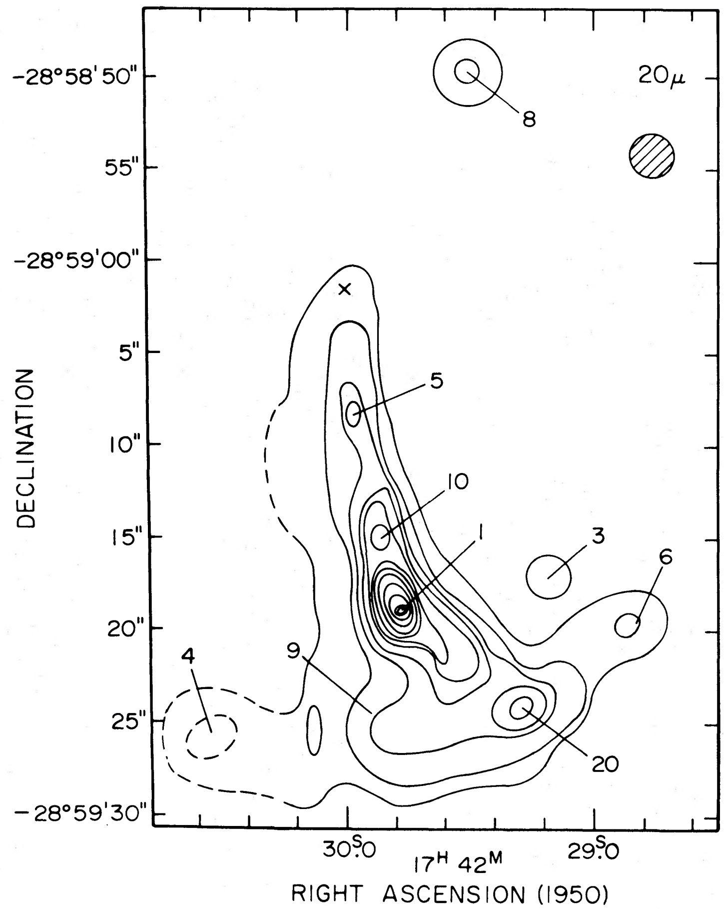

FIG. 2.—Map of the galactic-center region at 20 μm ($\Delta\lambda = 7$ μm) made with a 2''.3 circular diaphragm on the Hale 5 m telescope. The contour interval is 1.2×10^{11} Jy sr^{-1} (12 Jy per beam). The contour calibration is uncertain to a factor of 1.5 due to atmospheric extinction. The dashed contours were obtained from scans made with a 5'' circular diaphragm on the Hooker 2.5 m telescope.

TABLE 1

DE-REDDENED INTRINSIC MAGNITUDES OF GALACTIC-CENTER SOURCES*

Source	1.25 μm	1.65 μm	2.2 μm	3.5 μm	4.8 μm	8.7 μm	9.5 μm	11.2 μm	12.5 μm	20 μm
1...........	...	6.4	5.7	4.0	2.7	−2.1	−3.1	−3.4	−2.8	−3.8
2...........	...	...	...	...	...	−0.7	−1.6	−2.3	−2.1	> −2.3
3...........	...	...	...	3.7	1.7	−1.6	−1.3	−2.0	−2.2	−1.5
4...........	...	...	...	...	...	+1.0	+0.3	−1.1	−1.0	
5...........	...	...	...	...	...	−0.4	−1.1	−1.8	−1.2	−2.7
6...........	...	...	...	...	...	−0.5	−1.1	−1.8	−1.8	−2.1
7...........	6.1	4.6	4.0	3.1	3.0	+0.7	+0.3	−0.2	−0.5	> −1.1
8...........	...	> 10.6	7.4	4.7	3.1	−1.0	−1.4	−1.8	−1.5	−2.1
9...........	...	6.4	6.0	5.0	3.5	−0.8	−1.5	−2.3	−2.1	> −2.5
10...........	...	...	...	...	...	−1.4	−2.2	−2.6	−2.1	−3.1
11...........	...	6.2	6.1	5.8	5.4	...	...	...	...	
12...........	...	5.6	5.4	4.3	2.9	...	...	...	...	
16...........	...	5.7	5.6	5.0	3.6	...	...	...	...	
19...........	...	5.9	5.4	5.1	5.2	...	...	...	...	
20...........	...	...	...	...	...	−0.4	−1.2	−2.1	−1.9	−3.0
Extinction....	7.7	4.7	2.7	1.4	0.8	+2.4	+3.8	+2.8	+1.3	+0.9

* See text and Paper IV for discussion of uncertainties.

are given in Table 1 of Paper IV. For all measurements, except those of IRS 11 and IRS 19 at 4.8 μm, the statistical uncertainties are less than the probable systematic errors that are due to imperfect centering of the source in the diaphragm, loss of radiation due to seeing effects, and flux in the reference beam. At 20 μm the large and poorly known correction for atmospheric extinction is the dominant source of uncertainty. Except for one source, IRS 16, contamination in the reference beam was less than 20%; in the case of IRS 16, it was necessary to measure the flux in the reference position independently and to correct the data appropriately. As determined from remeasurement of a number of the sources on different nights, centering plus seeing errors were less than 0.2 mag. Overall, the infrared fluxes of individual sources should be accurate to better than 0.3 mag, except at 20 μm.

Spectrophotometric observations in the 8–13 μm range with 1% spectral resolution were made on seven nights in 1975 May and June. The observations were made at the Mount Wilson 2.5 m Hooker telescope and used a 5″ diaphragm and a 17″.5 beam separation in declination. The positions chosen are shown in Figure 1 of Paper II. It is seen there that, in general, the positions isolate individual sources as determined by the 2″.3 diaphragm. The seeing disk was typically 1″. The observation and reduction techniques were the same as described previously (Willner 1976); relative fluxes were obtained by assuming that the bright limb of the Moon radiates as a 350 K blackbody, and all fluxes were normalized to the 12.5 μm flux of α Sco, which was assumed to be 1.80×10^{-23} W m^{-2} Hz^{-1}. The results of the observations at seven positions are given in Figure 3.

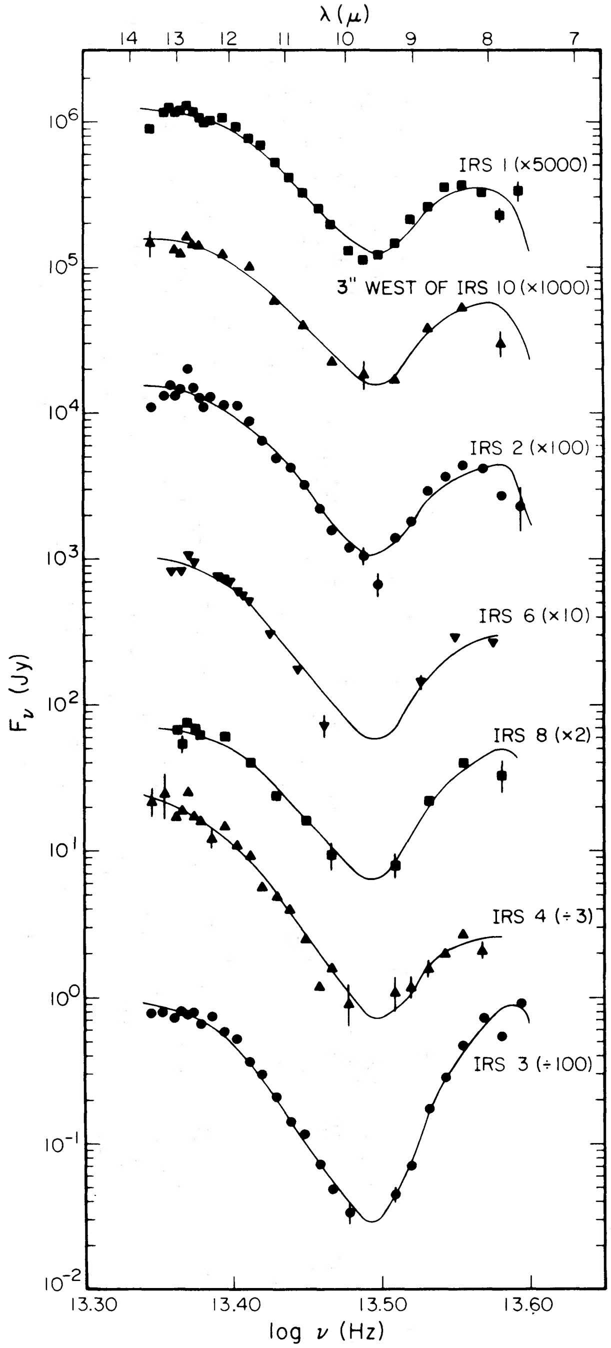

FIG. 3.—Observed fluxes from 7.5 to 13.5 μm obtained with a 1% spectral resolution and a 5″ circular diaphragm. Error bars are given for points whose statistical error exceeds 10%. The continuous lines represent fits (Willner 1976) to the spectrometer observations.

III. DISCUSSION—SOURCES BRIGHT AT 2 MICRONS

a) *IRS 11, 12, and 19*

Neugebauer *et al.* (1976) observed a CO absorption band near 2.3 μm in sources IRS 11 and 12 which they interpreted as originating in the photosphere of late-type stars. The 1–3 μm energy distributions of IRS 11 and 12, as well as of IRS 19, shown in Figure 4, are consistent with the interpretation that the sources are late-type stars. The rise in IRS 12 at 3.5 and 5 μm is probably due to contamination from the nearby source IRS 2, which is bright at 3.5 μm and longer wavelengths. The question of whether these discrete sources are single stars or clusters is still open. The sources are unresolved and less than 2″ in diameter. The absolute 2.2 μm magnitudes of all three sources are about −9. For luminosity class III, this corresponds to one M7 star, 20 M4 stars, or 100 K5 stars (Lee 1970). The extreme depth of the CO absorption in IRS 11 suggests that it could be an M8 star (Baldwin, Frogel, and Persson 1973). If the sources are supergiants, they could contain at most six stars, even if the stars are as early as K5 Ib. The total luminosity of each source depends on the effective temperature; the sources range from 1.5 to $3 \times 10^4 L_\odot$, if 2500 K (spectral type M7 [Lee 1970]) is assumed.

b) *IRS 7*

At 2.2 μm, IRS 7 is 4 times brighter than any other source within 1.5 pc of the galactic center (BN 75).

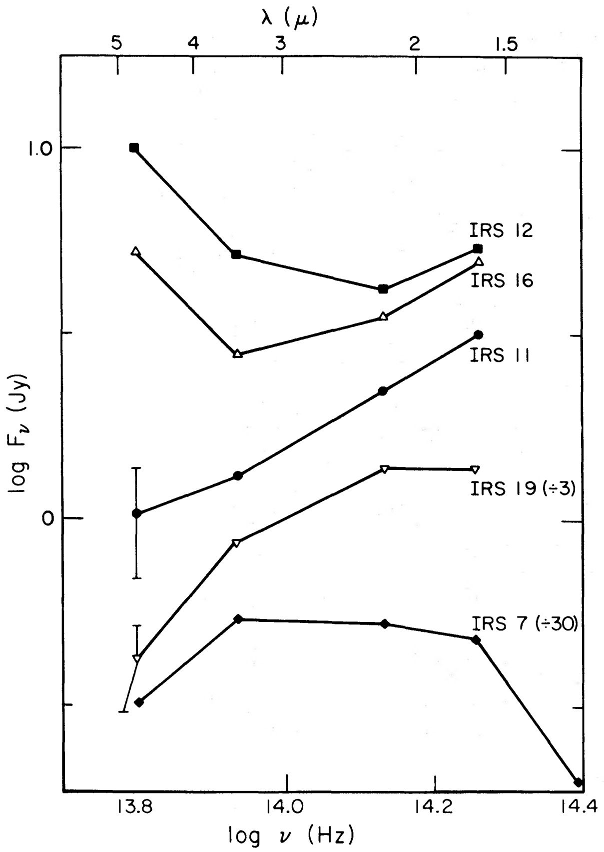

FIG. 4.—Energy distributions of IRS 12, 16, 11, 19, and 7 corrected for interstellar extinction. Uncertainties are discussed in the text.

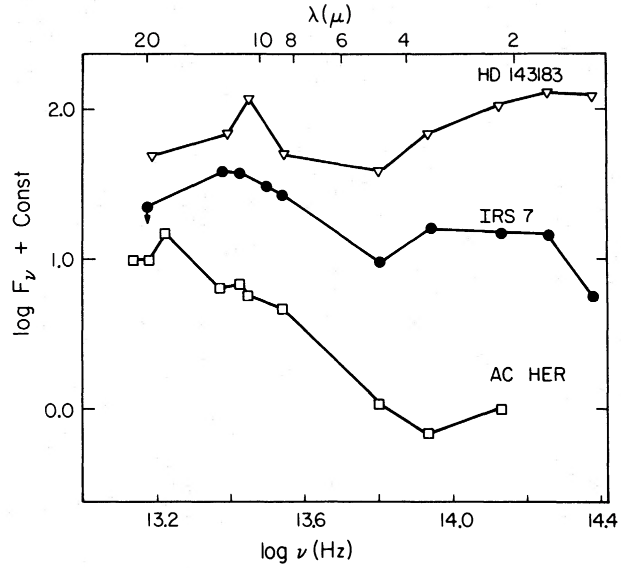

FIG. 5.—The 1–20 μm energy distribution of IRS 7 corrected for interstellar extinction. The ordinate is in arbitrary units. Also shown are the energy distributions of two stars; measurements and interstellar reddening corrections of HD 143183 are from Humphreys and Ney (1974), and the measurements of AC Her are from Gehrz (1972).

The presence of CO in absorption at 2.3 μm (Neugebauer *et al.* 1976; Soifer, Russell, and Merrill 1976; Treffers *et al.* 1976) suggests that the source is a star. The luminosity, the depth of the CO absorption, and the absence of C_2 absorption (Treffers *et al.* 1976) require that the object be similar to a late-type, oxygen-rich supergiant star.

Figure 5 shows the 1–20 μm energy distribution of IRS 7 corrected for interstellar extinction as described in Paper IV. The energy distributions of HD 143183 (Humphreys and Ney 1974) and AC Her (Gehrz 1972) are also shown for comparison. HD 143183 is an M3 Ia supergiant, while AC Her is an RV Tauri star. An additional reddening correction to the observations of IRS 7 amounting to 15% of the total would make the intrinsic 1.2–5 μm energy distribution of IRS 7 the same as that of HD 143183 within the uncertainties of the measurements and extinction corrections. IRS 7 would then be intrinsically fainter than HD 143183 by a factor of 3. If it is of the same spectral class as HD 143183, then its luminosity is about $10^5\,L_\odot$. In addition to HD 143183, many other M supergiants are known to have intrinsic luminosities of $\sim 10^5\,L_\odot$ (Lee 1970).

In a general sense, all three sources plotted in Figure 5 have similar energy distributions. If the additional extinction of 15% is applied to IRS 7, the spectra rise from 3.5 to 2.2 μm, where the flux is emitted by the stellar photospheres. The spectra also rise toward wavelengths longer than 5 μm. The 10 μm emission seen in all three stars in Figure 5 is probably due to circumstellar dust shells. The excess in IRS 7 is not an artifact of the extinction correction; even with no correction near 10 μm, there is still excess emission. The apparent absence of a silicate emission feature in IRS 7 similar to that seen in HD 143183 might be due to an underestimate of the silicate extinction, or the dust shell might lack silicates. In summary, it appears that IRS 7 has the properties of a late-type supergiant such as HD 143183 situated at the galactic center.

c) *IRS 16*

One of the most interesting sources in the galactic center is IRS 16. It has an energy distribution similar to the stellar source IRS 12 (Fig. 4), and its absolute 2.2 μm magnitude is about −9. The source is near the 10 μm ridge between IRS 1 and IRS 2, and the rise in flux at 5 μm is probably due to contamination. Neugebauer *et al.* (1976) found little or no CO absorption in this source; it is extended on a scale of ~2″ (0.1 pc) (BN 75). The map of BN 75 showed IRS 16 to be coincident with a nonthermal radio source (Balick and Brown 1974; Lo *et al.* 1975); the new position measurements presented in this paper indicate that the peak of IRS 16 may be 1″–2″ south of the nonthermal source.

One explanation of the nature of IRS 16, consistent with both its lack of strong CO absorption and its extended size, is that it is a star cluster whose members are giants considerably earlier than M0. For any reasonable population distribution, the stars producing most of the 2 μm radiation are the latest stars in the cluster, in this case K5–M0. About 100 giant stars, or 10^3 $M_\odot$, are required; this implies a density of 10^6 $M_\odot$ pc^{-3}. Another possibility is that the stellar population is dominated by dwarfs, which show no CO absorption band (Baldwin, Frogel, and Persson 1973), regardless of spectral type. As an example, if the stars are M4 dwarfs, 10^6 stars—or 10^5 $M_\odot$—are required; the density is then 10^8 $M_\odot$ pc^{-3}. For comparison, the centrally concentrated globular cluster NGC 6388 has a density of about 10^5 $M_\odot$ pc^{-3} within the central 0.6 pc radius (Illingworth and Freeman 1974). Thus, if either giants or dwarfs dominate the radiation, IRS 16 has a stellar density greater than a dense globular cluster. It should be pointed out that, other than the 1.64–3.5 μm colors, there is no concrete evidence that IRS 16 consists of stars.

d) *Extended 2.2 Micron Emission*

Because of its spatial similarity to the nucleus of M31, Becklin and Neugebauer (1968) attributed the extended 2.2 μm emission to radiation from unresolved stars. The present observations are consistent with this view. The average observed 1.65–2.2 μm color for the three discrete sources in which CO absorption has been detected is 2.3 mag, which agrees with the average color of the background over a 1'.8 diaphragm. The known discrete sources contribute only about 10% of the 2.2 μm radiation which is observed in the 1'.8 area. Thus the 1.65–2.2 μm color of the extended background is similar to that of discrete sources known to be stars. Since the 1.65–2.2 μm color of all stars is nearly the same, it can be concluded that the observed color of the extended 2.2 μm emission is consistent with its being produced by unresolved stars.

IV. DISCUSSION—SOURCES BRIGHT AT 10 MICRONS

a) *Ridge Sources—IRS 1, 2, 5, 6, 9, and 10*

The map of Figure 1 shows these six sources strung in an arc along a ridge of 10 μm emission. The energy distributions of these sources resemble those of compact H II regions or planetary nebulae in that they are bright at 10 μm but relatively faint at 2 μm (BN 75). The sizes of about 0.1 pc are also comparable to the sizes of dense H II regions such as the Orion Nebula or planetary nebulae. Figure 6 shows the extinction-corrected energy distributions of IRS 1 and IRS 9 from 1.65 to 20 μm, and Figure 7 shows the 8.7–12.5 μm fluxes of all of the ridge sources. None of the sources seems to have any silicate absorption, but if the extinction corrections that were applied are correct, then all show intrinsic silicate emission typical of optically thin silicate dust. The energy distributions of these discrete sources are considerably hotter than the background; see also RL 73. This indicates that each contains its own source of luminosity.

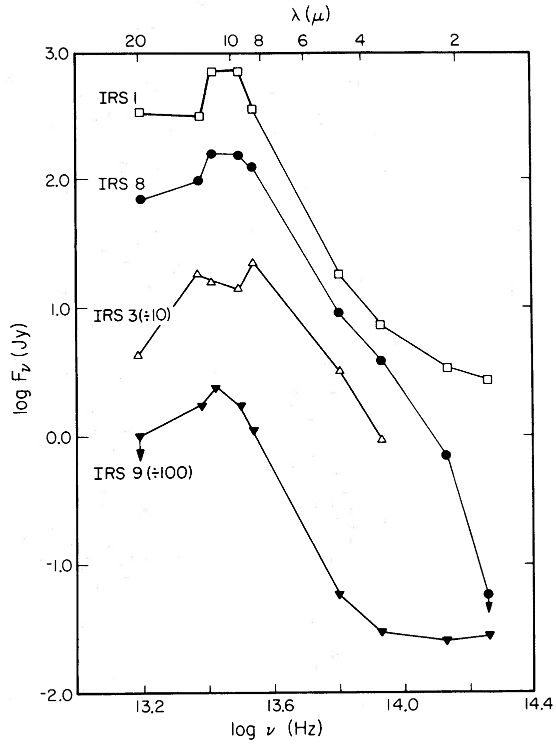

FIG. 6.—The 1–20 μm energy distributions of IRS 1, 8, 3, and 9 corrected for interstellar extinction.

The luminosity of IRS 1, estimated from the 1–20 μm flux observation, is about $5 \times 10^5\, L_\odot$; the other sources radiate between 1 and $2 \times 10^5\, L_\odot$. BN 75 suggested that these sources had linear sizes and luminosities similar to those of the planetary nebula NGC 7027. Because of the extinction correction, particularly in the 10 μm silicate band, the luminosities found here are about 10 times larger than those quoted by BN 75. Furthermore, NGC 7027 may be nearer (Cudworth 1974) and thus less luminous than assumed by BN 75. For these reasons, it appears that the ridge sources are too luminous to be normal planetary nebulae. Further reasons for doubting that the sources are normal planetaries are given by Alloin, Cruz-González, and Peimbert (1976). From a luminosity standpoint, the sources are more similar to compact galactic H II regions. They are different from most compact H II regions in three ways. First, there is no indication of enhanced ionized gas at the position of individual compact sources, as determined from the Ne II emission line at 12.8 μm (Paper II). Recent observations of the Bγ line at 2.17 μm tend to confirm this result (Paper III). Second, as shown in Figure 6, the flux density at 20 μm is less than or about equal to that at 10 μm, whereas in galactic H II regions there is a large increase in flux density from 10 to 20 μm (see, e.g., Wynn-Williams and Becklin 1974). Third,

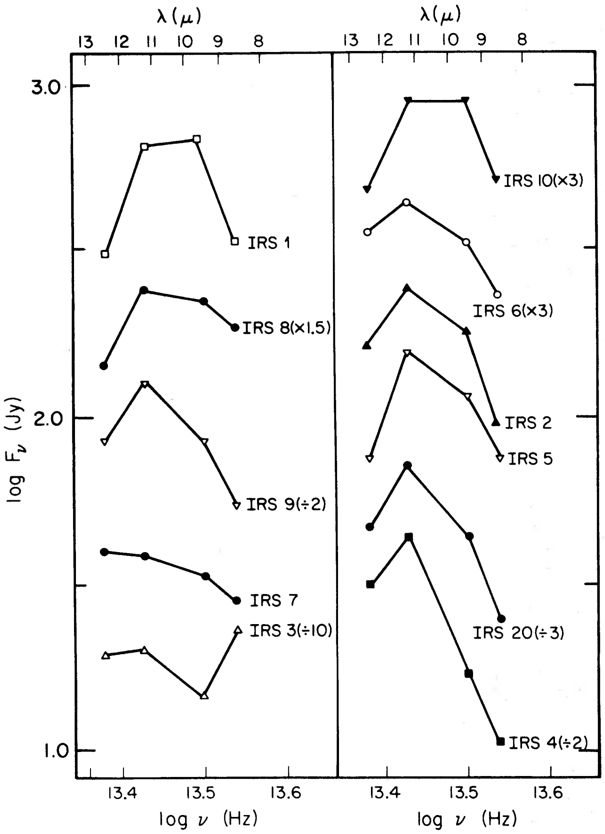

FIG. 7.—The 8–13 μm energy distributions of 11 sources corrected for interstellar extinction.

there is no silicate absorption, which is often present in compact H II regions (Gillett *et al.* 1975*a*; Willner 1976). The above evidence would indicate that these sources are not typical compact H II regions and could be unique in the Galaxy.

At least two of the ridge sources appear to be composite, showing evidence of emission by stars. Figure 6 shows that the flux of IRS 9 rises from 2.2 to 1.65 μm; the color is within the range of colors of sources that are interpreted as being stars. IRS 1 is redder than sources interpreted as being stellar, but marginal evidence for CO absorption at 2.3 μm (Neugebauer *et al.* 1976) indicates that stars may be present in or near the source. It is thus possible that some of the ridge sources are associated with stellar clusters.

b) *Extended Emission*

Approximately one-fourth of the 10 μm flux from the region 2 × 2 pc^2 is due to low-surface-brightness emission which is not spatially resolved; additional low-surface-brightness 10 μm radiation is missing from the map because of instrumental effects. There is no small-scale correlation between the extended 2.2 and 10 μm emission. RL 73 found the color of the extended emission to be much redder in the 5–20 μm region than that of the compact sources discussed in the previous sections.

Far-infrared maps of the galactic center with 0$'$.5 resolution (Harvey, Campbell, and Hoffmann 1976) and 1$'$ resolution (Gatley *et al.* 1977) have shown an extended source which is centered near the ridge and whose energy distribution peaks near 50 μm. The extended background observed at 10 and 20 μm, because of its very red color, is likely to be the short-wavelength manifestation of the far-infrared source. According to Gatley *et al.* (1977), the far-infrared source is thought to be thermal emission from uniformly distributed dust at the galactic center heated by the high density of ultraviolet and visual photons which come from the large number of stars within the region. This same ultraviolet radiation is believed to produce the thermal radio source Sgr A (Ekers *et al.* 1975). A review of the radio and infrared observations is given by Oort (1977).

c) *IRS 4 and 20*

The energy distributions of IRS 4 and of the extended background are shown in Figure 4 of RL 73. It is seen there that IRS 4 is significantly cooler than the other discrete sources and has an energy distribution like that of the extended background. In fact, IRS 4, which is itself extended on the order of 5$''$, may be a condensation in the general background. The energy distribution of IRS 20, which is seen conspicuously only on the 20 μm map, is included in Figure 7. It is redder than the other discrete sources, although it is not as red as the extended background.

d) *IRS 3 and 8*

IRS 3 is a unique source in the galactic-center complex, because it is an isolated, unresolved object and has a larger observed silicate absorption than any other source (Fig. 3). In fact, when the observed spectra are corrected for interstellar extinction, IRS 3 is the only source with intrinsic silicate absorption (Fig. 7); the optical depth of this absorption is at least 1.3. As shown in Figure 6, IRS 3 has a bluer energy distribution at wavelengths between 5 and 20 μm than do the ridge sources IRS 1 and IRS 9.

In terms of its small size, relatively warm energy distribution, and the presence of a silicate absorption feature, IRS 3 is similar to other galactic infrared sources, such as the BN source in the Orion Nebula (Becklin, Neugebauer, and Wynn-Williams 1973) or the 1612 MHz OH sources studied by Evans and Beckwith (1977). Sources like the former object are associated with giant molecular clouds. Although the presence of a molecular cloud at the galactic center neither has been established nor can be ruled out, the uniformity of the 2 μm extinction across the face of the region (Paper IV) makes such a possibility unlikely. The OH sources are thought to be late-type Mira stars which have undergone a large amount of mass loss (Evans and Beckwith 1977). The luminosity of IRS 3 corrected for extinction is about 3 × 10^4 $L_\odot$, very similar to the 1612 MHz emitting infrared stars.

The nature of IRS 8 is unknown. It has an energy distribution (Fig. 6) and a silicate emission (Fig. 7) like those of the ridge sources; it has been spatially resolved (BN 75).

V. CONCLUSIONS

The simplest objects to identify among the galactic-center sources are stars. The most prominent of these, IRS 7, is interpreted as being a late-type supergiant; other assumed stellar sources appear to be very late-type giants which have lower luminosity. IRS 16, which is the source nearest the nonthermal radio source, is proposed to be a cluster of relatively early-spectral-type giants or of dwarfs. In either case, the mass density implied is greater than $10^6 M_\odot$ pc^{-3}. This might therefore be the position of highest stellar density in the Galaxy.

Heated dust is likely to be responsible for the emission in those sources which radiate most prominently at 10 μm and longer wavelengths. Many of the properties of the isolated source IRS 3 are similar to those of extremely red OH–emitting infrared stars. Other sources have some, but not all, of the properties of compact H II regions or of planetary nebulae. The dust producing the infrared radiation is optically thin. A stellar component appears to be present in some of the sources; they might therefore be dusty star clusters. The extended emission seen at 10 and 20 μm is believed to be the short-wavelength extension of the radiation seen at 30–100 μm.

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REFERENCES

Alloin, D., Cruz-González, C., and Peimbert, M. 1976, *Ap. J.*, **205**, 74.
Baldwin, J. R., Frogel, J. A., and Persson, S. E. 1973, *Ap. J.*, **184**, 427.
Balick, B., and Brown, R. L. 1974, *Ap. J.*, **194**, 265.
Becklin, E. E., Matthews, K., Neugebauer, G., and Willner, S. P. 1978, *Ap. J.*, **220**, in press (Paper IV).
Becklin, E. E., and Neugebauer, G. 1968, *Ap. J.*, **151**, 145.
———. 1969, *Ap. J.* (*Letters*), **157**, L31.
———. 1975, *Ap. J.* (*Letters*), **200**, L71 (BN 75).
Becklin, E. E., Neugebauer, G., and Wynn-Williams, C. G. 1973, *Ap. J.* (*Letters*), **182**, L7.
Beckwith, S., Evans, N. J., II, Becklin, E. E., and Neugebauer, G. 1976, *Ap. J.*, **208**, 390.
Cudworth, K. M. 1974, *A.J.*, **79**, 1384.
Ekers, R. D., Goss, W. M., Schwarz, U. J., Downes, D., and Rogstad, D. 1975, *Astr. Ap.*, **43**, 159.
Evans, N. J., II, and Beckwith, S. 1977, *Ap. J.*, **217**, 729.
Gatley, I., Becklin, E. E., Werner, M. W., and Wynn-Williams, C. G. 1977, *Ap. J.*, **216**, 277.
Gehrz, R. D. 1972, *Ap. J.*, **178**, 715.
Gillett, F. C., Forrest, W. J., Merrill, K. M., Capps, R. W., and Soifer, B. T. 1975*a*, *Ap. J.*, **200**, 609.
Gillett, F. C., Jones, T. W., Merrill, K. M., and Stein, W. A. 1975*b*, *Astr. Ap.*, **45**, 77.
Harvey, P. M., Campbell, M. F., and Hoffmann, W. F. 1976, *Ap. J.* (*Letters*), **205**, L69.
Humphreys, R. M., and Ney, E. P. 1974, *Ap. J.*, **194**, 623.
Illingworth, G., and Freeman, K. C. 1974, *Ap. J.* (*Letters*), **188**, L83.
Lee, T. A. 1970, *Ap. J.*, **162**, 217.
Lo, K. Y., Schilizzi, R. T., Cohen, M. H., and Ross, H. N. 1975, *Ap. J.* (*Letters*), **202**, L63.
Low, F. J., Kleinmann, D. E., Forbes, F. F., and Aumann, H. H. 1969, *Ap. J.* (*Letters*), **157**, L97.
Neugebauer, G., Becklin, E. E., Beckwith, S., Matthews, K., and Wynn-Williams, C. G. 1976, *Ap. J.* (*Letters*), **205**, L139.
Neugebauer, G., Becklin, E. E., Matthews, K., and Wynn-Williams, C. G. 1978, *Ap. J.*, **220**, in press (Paper III).
Oort, J. H. 1977, *Ann. Rev. Astr. Ap.*, **15**, in press.
Rieke, G. H. 1974, *Ap. J.* (*Letters*), **193**, L81.
Rieke, G. H., and Low, F. J. 1973, *Ap. J.*, **184**, 415 (RL 73).
Soifer, B. T., Russell, R. W., and Merrill, K. M. 1976, *Ap. J.* (*Letters*), **207**, L83.
Treffers, R. R., Fink, U., Larson, H. P., and Gautier, T. N., III. 1976, *Ap. J.* (*Letters*), **209**, L115.
van de Hulst, H. C. 1946, *Recherches Astr. Obs. d'Utrecht*, Vol. **11**, part 1.
Willner, S. P. 1976, *Ap. J.*, **206**, 728.
———. 1978, *Ap. J.*, **219**, in press (Paper II).
Wynn-Williams, C. G., and Becklin, E. E. 1974, *Pub. A.S.P.*, **86**, 5.

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