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SUBMILLIMETER OBSERVATIONS OF THE GALACTIC CENTER

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ABSTRACT

We have mapped a 15′ × 15′ region surrounding Sgr A at a mean wavelength of 540 μm. The principal feature is a ridge about 10′ long running parallel to the galactic equator and approximately centered on Sgr A but with no peak at that point. The ridge coincides with the 25 and 55 km s^{-1} clouds seen in molecular line observations. We estimate the mass of the clouds and discuss their positions with respect to the galactic center.

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

I. INTRODUCTION

We present in this *Letter* the results of submillimeter observations of the galactic center. The observed spatial distribution differs strikingly from the distributions which have been mapped at infrared and radio wavelengths but is closely related to that for molecular line absorption and emission. The region of highest dust column density coincides with the region of highest ammonia and formaldehyde emission and hence with a region of high gas spatial density. The total mass of gas and dust inferred from the submillimeter emission is within the range of masses inferred from the observed velocity gradients where the gradients are assumed to be due to rotation of gravitationally bound clouds.

II. OBSERVATIONS

In Figure 1 we show the submillimeter map of the region surrounding Sgr A. The observations were made with the 4 m telescope at the Cerro Tololo Inter-American Observatory in 1976 July and 1977 June. The beam diameters (full width at half-maximum) were 83″ (1976) and 110″ (1977). The reference-beam spacings (in R.A.) were 200″ (1976) and 300″ (1977). Signals for individual points were obtained by repetitive beam-switching at a fixed position. The signal from a point near the emission peak was measured periodically to monitor the atmospheric transmission. Sampling intervals were 5^s in right ascension and 2′ in declination.

The data were deconvolved to remove the effect of flux in the reference beams, assuming zero flux at the extreme eastern and western ends of the scans where no signal was observed. At the submillimeter peak the correction for flux in the reference beams was ~50% with 200″ beam spacing (1976) and ~15% with 300″ beam spacing (1977). Statistical noise and systematic errors in the deconvolution process contributed about equally to a total uncertainty of about one contour interval. The scan at −29°07′ was not extended far enough east and west to move both reference beams entirely off the peak. Hence the deconvolution at that declination was based in part on continuity with the adjacent scan, and the uncertainties were correspondingly increased. Nevertheless, the data clearly show a steep falloff below −29°05′.

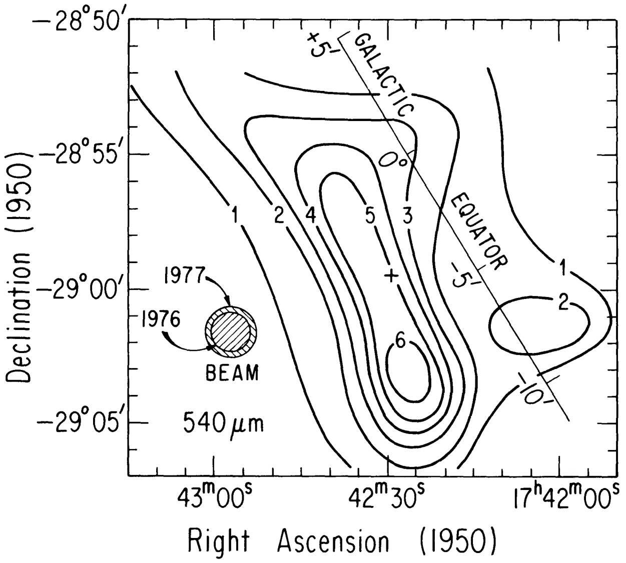

FIG. 1.—Submillimeter map of the Sgr A region. The flux density at the peak is (530 ± 200) Jy into an 83″ diameter beam. The total for the entire mapped area is ~12,000 × 10^{-26} Jy. The contour interval is 80 Jy into an 80″ diameter beam. (1 Jy = 10^{-26} W m^{-2} Hz^{-1}.)

The peak flux density into the 83″ beam was (530 ±

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200) $\times 10^{-26}$ W m^{-2} Hz^{-1} at a flux-weighted mean wavelength of 540 μm. The dominant contribution to the error in the peak flux is the uncertainty in the atmospheric water vapor and the shape of the source spectrum. Our value for the mean wavelength corresponds to a ν^4 source spectrum; the uncertainty quoted is large enough to accommodate an error of ± 1 in the spectral index. Further details of the instrumentation, calibration, and atmospheric corrections have been presented by Hildebrand *et al.* (1977).

III. DISCUSSION

a) General Characteristics of the Source

The submillimeter map, unlike the radio continuum map of Pauls *et al.* (1976) and the far-infrared maps of Fazio (1977) and Gatley *et al.* (1977), shows no feature which is clearly associated with the radio point source in Sgr A West (Fig. 1, 2). There is general agreement, however, between the position of the main ridge of submillimeter emission and the regions of strongest molecular line emission and absorption (Fig. 3). From these comparisons we infer that the submillimeter radiation is emitted primarily by dust in the molecular clouds where the dust temperature is lower and the column density much higher than at Sgr A West.

b) Positions of the Principal Clouds

Molecular clouds lying approximately along the main ridge of submillimeter emission have been seen in observations of several molecular lines, including CO (Fig. 3*a*), OH (Fig. 3*b*), HCN (Fig. 3*c*), and H_2CO (Whiteoak, Rogstad, and Lockhart 1974). For each of the molecular species CO, OH, and H_2CO, two primary radial-velocity components, $v \approx +25$ km s^{-1} and $v \approx +55$ km s^{-1}, have been observed. The centers of the two clouds are separated by a few minutes of arc, but the edges overlap along the line of sight. Hence the clouds are unresolved in the submillimeter continuum. The peak CO emission temperatures, the OH absorption optical depths, and the dust column densities of the two clouds are approximately the same. A greater central density for the southern cloud is indicated by the detection of NH_3 and H_2CO emission (Knowles and Cheung 1971; Thaddeus *et al.* 1971) of radial velocity 25 km s^{-1} near the submillimeter peak (Fig. 3*a*). Maps of CO emission by Solomon *et al.* (1972), with lower resolution but broader spatial coverage than those of Liszt, Sanders, and Burton (1975) (Fig. 3*a*), show that the CO source has a size comparable to that of the submillimeter ridge. The apparent displacement of the OH contours (mapped with 3ʹ.25 beam diameter) from the submillimeter ridge (Fig. 3*b*) does not appear in the higher-resolution map of Sandqvist (1974).

From the absence of H_2CO absorption in front of Sgr A West, Whiteoak, Rogstad, and Lockhart (1974) and Oort (1974) have argued that the clouds must be behind Sgr A West and in front of Sgr A East. This conclusion has been questioned by Liszt, Sanders, and Burton (1975), who observe a CO emission minimum at the position of Sgr A West, and by Rieke, Telesco, and Harper (1977), who argue that there is evidence for absorption of infrared radiation from the galactic center region by foreground molecular clouds. The submillimeter data lend support to the latter view for the 25 km s^{-1} cloud. The region of greatest dust column density, as indicated by the submillimeter peak, coincides with a minimum in surface brightness on the 2.2 μm map of Becklin, Neugebauer, and Early (1974; Fig. 3*d*) and with a region of strong H_2CO absorption (Whiteoak, Rogstad, and Lockhart 1974). The 2.2 μm map shows no comparably dark area in the vicinity of

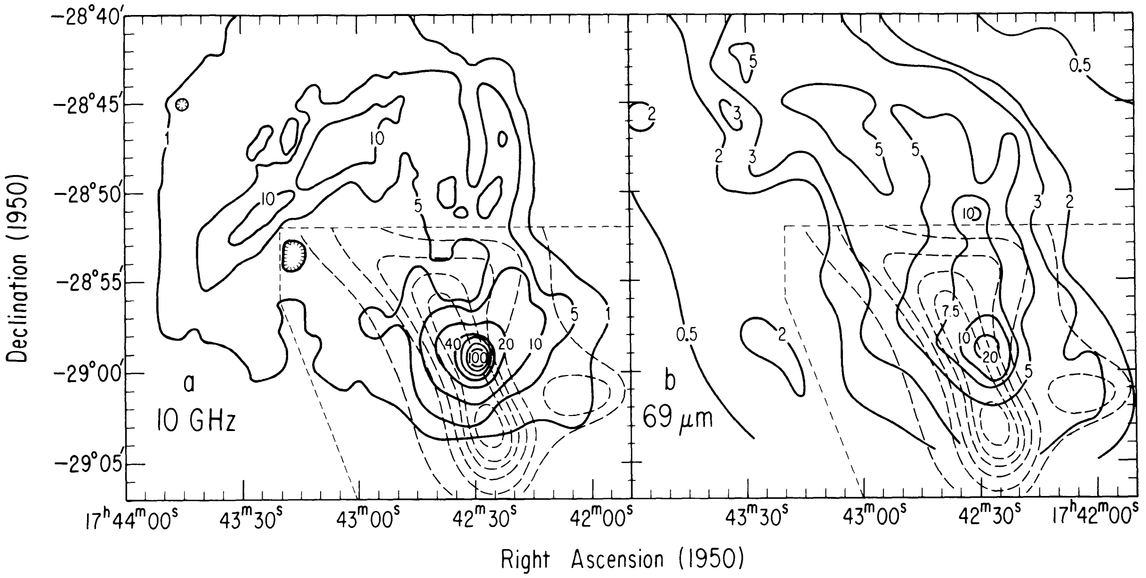

FIG. 2.—Comparisons of submillimeter map (*dashed contours*) with radio continuum and far-infrared maps. *Dashed lines*, boundaries of the submillimeter map. (*a*) 10 GHz (Pauls *et al.* 1976). (*b*) 69 μm (Fazio 1977).

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the 55 km s^{-1} cloud, but, as pointed out by Rieke, Telesco, and Harper (1977), absorption in that region could be masked by foreground stars still associated with the nuclear bulge.

c) *Dust Column Density and Mass*

The estimation of dust column density, D, and dust mass, M_d, from measured values of the submillimeter optical depth, τ_s, has been discussed by Westbrook *et al.* (1976) and by Hildebrand *et al.* (1977). In a homogeneous population of grains, the quantities D and τ_s are proportional. For the ratio D/τ_s, or $4\rho a/3Q$ in the notation of the above papers, we assume the value 4/3 g cm^{-2} at 500 μm and a frequency dependence, $\tau_s \propto \nu^2$ (Hildebrand *et al.* 1977). On that basis, the value at 1 mm is 4 times higher than that assumed by Westbrook *et al.* (1976), a systematic difference entering into mass comparisons.

Since we measure the flux density at frequencies such that $h\nu/kT \ll 1$ (assuming $T \gtrsim 20$ K), the derived values of τ_s and M_d depend only linearly on T. We shall assume $T = 30$ K and a distance of 10 kpc. A comparison of the far-infrared and submillimeter maps (Fig. 2*b*) shows that the ratio of far-infrared to submillimeter

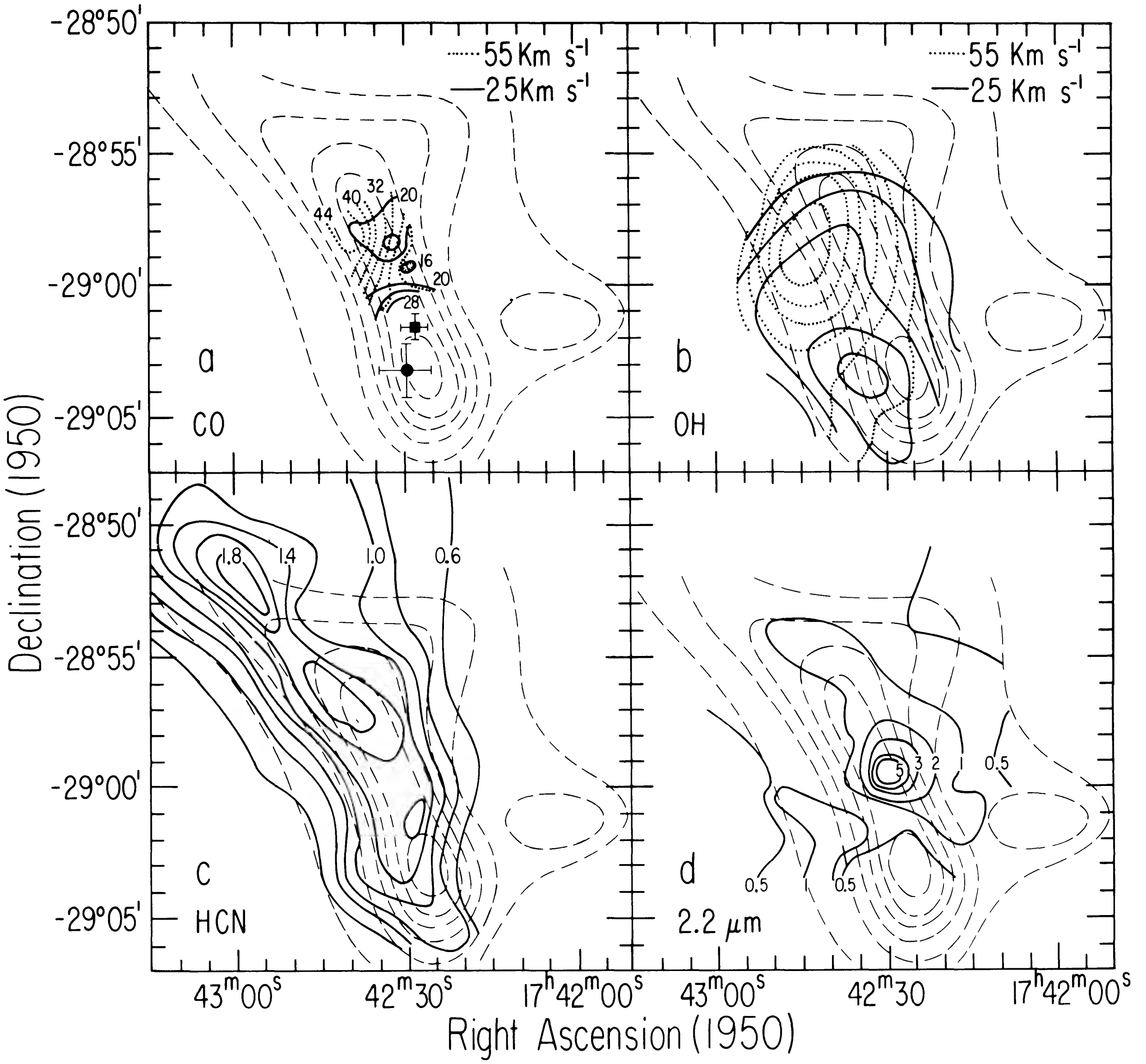

FIG. 3.—Comparison of submillimeter map with molecular line and 2.2 μm maps. (*a*) CO emission (Liszt, Sanders, and Burton 1975). The contours represent average brightness temperatures for the intervals 20 to 30 km s^{-1} and 50 to 60 km s^{-1}. *Circle*, position for NH_3 emission (Knowles and Cheung 1971); *square*, peak position for H_2CO emission (Thaddeus *et al.* 1971). (*b*) 1667 MHz OH absorption (Bieging 1976). (*c*) HCN emission (Fukui *et al.* 1977). The contours represent maximum antenna temperatures for the 3.4 mm line. (*d*) 2.2 μm (map of Becklin, Neugebauer, and Early 1974, as represented by Gatley *et al.* 1977). The contour interval is equivalent to 3 × 10^{-26} W m^{-2} Hz^{-1} into a 1′ diameter beam.

emission varies by less than a factor of 2 in the region above our second contour and away from Sgr A West. For a population of grains at $T \approx 30$ K, this corresponds to a temperature variation of less than ± 5 K. The available spectral data, however, are insufficient to exclude the possibility that separate populations of higher- and lower-temperature grains are superposed along the line of sight.

At the submillimeter peak we find an optical depth $\tau_s = 0.02$ and a dust column density $D = 0.03$ g cm^{-2}. For the entire mapped area, we derive a dust mass $4 \times 10^4\ M_\odot$ with an uncertainty of about one order of magnitude due to uncertainties in the grain parameters (Hildebrand *et al.* 1977). With a gas-to-dust mass ratio of 100, the total mass of the molecular clouds would be $4 \times 10^6\ M_\odot$. In Table 1 we compare this value with estimates based on molecular line observations. The kinematic mass estimates given in the table are based on the assumption that the observed velocity gradients are due to rotation of the dust clouds about their own centers and that the clouds are gravitationally self-bound. Our value is within the range of the kinematic estimates and is therefore consistent with those assumptions.

TABLE 1

COMPARISON OF MASS ESTIMATES FOR SGR A CLOUDS

Authors	Mass ($M_\odot$)*	Method
Solomon *et al.* 1972.......	$\geq 2\times10^5$	CO optical depth
Fomalont and Weliachew 1973..................	3×10^5	Kinematics (H_2CO)
Sandqvist 1974...........	$\geq 4\times10^5$	Kinematics (OH)
Bieging 1976.............	$\geq 6\times10^6$	Kinematics (OH)
This work...............	4×10^6†	Submillimeter thermal radiation

* Total mass in mapped area.

† Based on assumed gas-to-dust ratio of 100.

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