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MOLECULAR EMISSION WHICH IS PROBABLY LOCALIZED WITHIN THE CENTRAL 10 PARSECS OF THE GALAXY

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ABSTRACT

We report detection of molecular emission at $v \approx -140$ km s^{-1} to -30 km s^{-1} localized within a few arc minutes of Sgr A West in the 1–0 line of HNC. The molecular gas is likely associated with the galactic center. This indicates that complex molecules do exist within the central 10 pc of the Galaxy. Spatial distribution of the molecular gas is asymmetric with respect to the galactic center, and it appears likely that the gas is not purely rotating but is moving radially into or out of the galactic center. We estimate the duration of the phenomenon to be $\lesssim 5\text{–}10 \times 10^4$ years.

Subject headings: galaxies: Milky Way — galaxies: nuclei — interstellar: molecules

I. INTRODUCTION

It has been known for a few years that there are ionized cloudlets in the central parsec of the Galaxy mainly from the [Ne II] observations (e.g., Lacy *et al.* 1980). Subsequent detection of [O I] emission from the same direction has shown there is also an appreciable amount of neutral matter in the close vicinity of the galactic center (Lester *et al.* 1981; Genzel *et al.* 1982). More recently, the vibrational-rotational transition of molecular hydrogen was observed within 1′ of Sgr A West (Gatley 1982). There has not yet been any direct evidence for the existence of complex molecules within the central several parsecs of the Galaxy.

The well-known 50 km s^{-1} and 30 km s^{-1} molecular clouds lie within a few tens of arc minutes of Sgr A West (Fukui *et al.* 1977; Fukui *et al.* 1980). Toward Sgr A West, the clouds show a significant depression of emission intensity in some molecular lines which are relatively fragile to the ultraviolet radiation such as HC_3N and H_2CO (Fukui *et al.* 1982; Fukui *et al.* 1984). This provides an indirect evidence for the close proximity of the clouds to the galactic center. A firm detection of complex molecules in this region is important because molecular line data may give constraints on the mass and the radiation spectrum of the central compact object in Sgr A West as well as on its environments.

In this *Letter*, we report the detection of high-velocity molecular emission which is localized in the central 10 pc of the Galaxy based on HNC observations at 3.3 mm wavelength.

II. OBSERVATIONS AND RESULTS

Observations were made in 1982 July with the NRAO[3] 11 m telescope on Kitt Peak. The half-power beam width at 3.3 mm was 70″. A dual polarization receiver with a system temperature of 400 K single-sideband (SSB) per channel was used. Intensity calibration was performed by looking at an ambient temperature absorbing material and a cold load (~ 15 K). Pointing was checked by observing Venus and was accurate within 15″.

Because the emission-line spectra in the galactic center region are generally very broad, we payed special care to obtaining flat spectral baselines. Observations were done by position switching every 30 s with reference points at the same elevation angle. To eliminate standing waves between the feed and the subreflector, the path length was varied by a corner cube reflector. The observations were part of the mapping of the Sgr A molecular cloud in the emission lines of HNC (1–0; 90.664 GHz) and HC_3N (11–10; 100.076 GHz). In this *Letter* we deal with the HNC data near Sgr A West, although a fuller account of the observations will be described in a forthcoming paper (Fukui *et al.* 1984). A 256 channel, 1 MHz filter-bank spectrometer was used usually in a parallel mode. It gave a velocity resolution of 3.3 km s^{-1} and a velocity coverage of 420 km s^{-1} at 3.3 mm. The observed area is approximately $\pm 10'$ in l and $\pm 3'$ in b with a grid separation of 90″.

Figure 1 shows the HNC spectrum toward Sgr A West. We find a significant negative velocity emission

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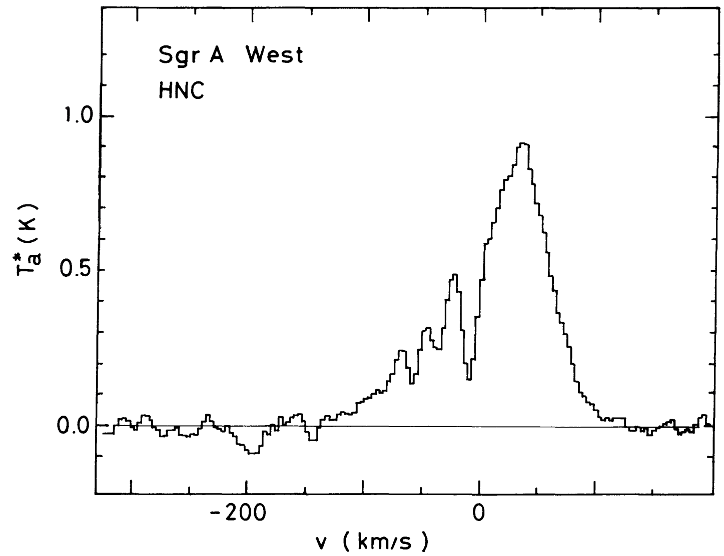

FIG. 1.—The HNC (1–0) spectrum at 3.3 mm toward Sgr A West (R.A. [1950] = $17^h42^m29^s.5$, decl. [1950] = $-28°59'19''$). Velocity is referred to the local standard of rest. The negative velocity emission up to -140 km s^{-1} is significant. Three dips at approximately -10, -30, and -55 km s^{-1} are probably caused by foreground arms. A dip at -190 km s^{-1} below the baseline level is probably an absorption of the radio continuum radiation from Sgr A West whose antenna temperature with the NRAO 11 m telescope is approximately 0.3 K. Only this spectrum was taken by a 256 MHz instantaneous bandwidth (= 840 km s^{-1} at 3.3 mm), and the baseline was determined from channels including adjacent channels which are not shown in the figure. The spectrum is smoothed by a 3 point box car weighting.

down to approximately -140 km s^{-1}. Three dips at negative velocities are probably self-absorption features due to foreground cold HNC gas (see Linke, Stark, and Frerking 1981). Furthermore, we find a dip below the baseline level at $v \sim -190$ km s^{-1}. It is probably absorption against the Sgr A West radio continuum source. A profile map around Sgr A West is shown in Figure 2. The profile toward Sgr A West in the figure was obtained with an integration time of about one-sixth of that in Figure 1. We find the negative velocity emission from -30 km s^{-1} to -140 km s^{-1} is localized near Sgr A West. We see appreciable emission in the velocity range only at two points; (0, 0) and (-1.5, 0). There are weaker signs of the negative velocity emission at some other neighboring points; (-1.5, -1.5), (0, -1.5), (1.5, -1.5), (1.5, 0), and (1.5, 1.5). We find no evidence of the negative velocity emission in either of the other spectra taken in the whole observed area ($\pm 10'$ in l and $\pm 3'$ in b). Therefore, the negative velocity emission from -140 km s^{-1} to -30 km s^{-1} is localized within a few arc minutes of Sgr A West. From the profile map in Figure 2, we notice that the negative velocity emission is distributed along the galactic plane, and we roughly estimate its size to be approximately $3' \times 1'.5$ (= 9 pc $\times$ 4.5 pc) in l and b. The distribution of the integrated intensity at the velocity range has its maximum at (-1.5, 0). Thus, the negative velocity emission is distributed mostly on the negative galactic longitude side of Sgr A West.

It may be interesting to ask if there is any counterpart of the negative velocity emission in the positive velocity. A careful look at Figure 2 leads to a finding that there is a weak emission of approximately 0.1–0.2 K at 80–100 km s^{-1} in four of the spectra: (0, 0), (0, 1.5), (1.5, 0), and (1.5, 1.5) [indicated by an arrow at (1.5, 1.5)]. The emission is also found in some spectra not shown in Figure 2, and its spatial extent is much larger than that of the negative velocity emission. Therefore, there is no appearance of symmetry between material of positive and negative velocities on the two sides of the galactic center.

III. DISCUSSION

a) Mass and Location of the Negative Velocity Emission

For assumed HNC abundances, [HNC]/n, of $\lesssim 3 \times 10^{-8}$, we find that densities of $\gtrsim 2 \times 10^3$ cm^{-3} are required in order to explain the observed intensity in the negative velocity emission when we use the large velocity gradient approximation. Here we assume a velocity gradient in the line of sight of 10 km s^{-1} pc^{-1}, which is obtained as the velocity span of the negative velocity emission divided by its apparent size. The HNC abundance of 3×10^{-8} is likely a secure upper limit when we refer to theoretical estimates of the HCN abundance (Mitchell, Ginsburg, and Kuntz 1978) and observed HNC/HCN ratios (Goldsmith *et al.* 1981). Therefore, the density 2×10^3 cm^{-3} should give a secure lower limit. We get the total mass of the negative velocity gas to be $\gtrsim 1.6 \times 10^4$ $M_\odot$, and the column density is $\gtrsim 3$

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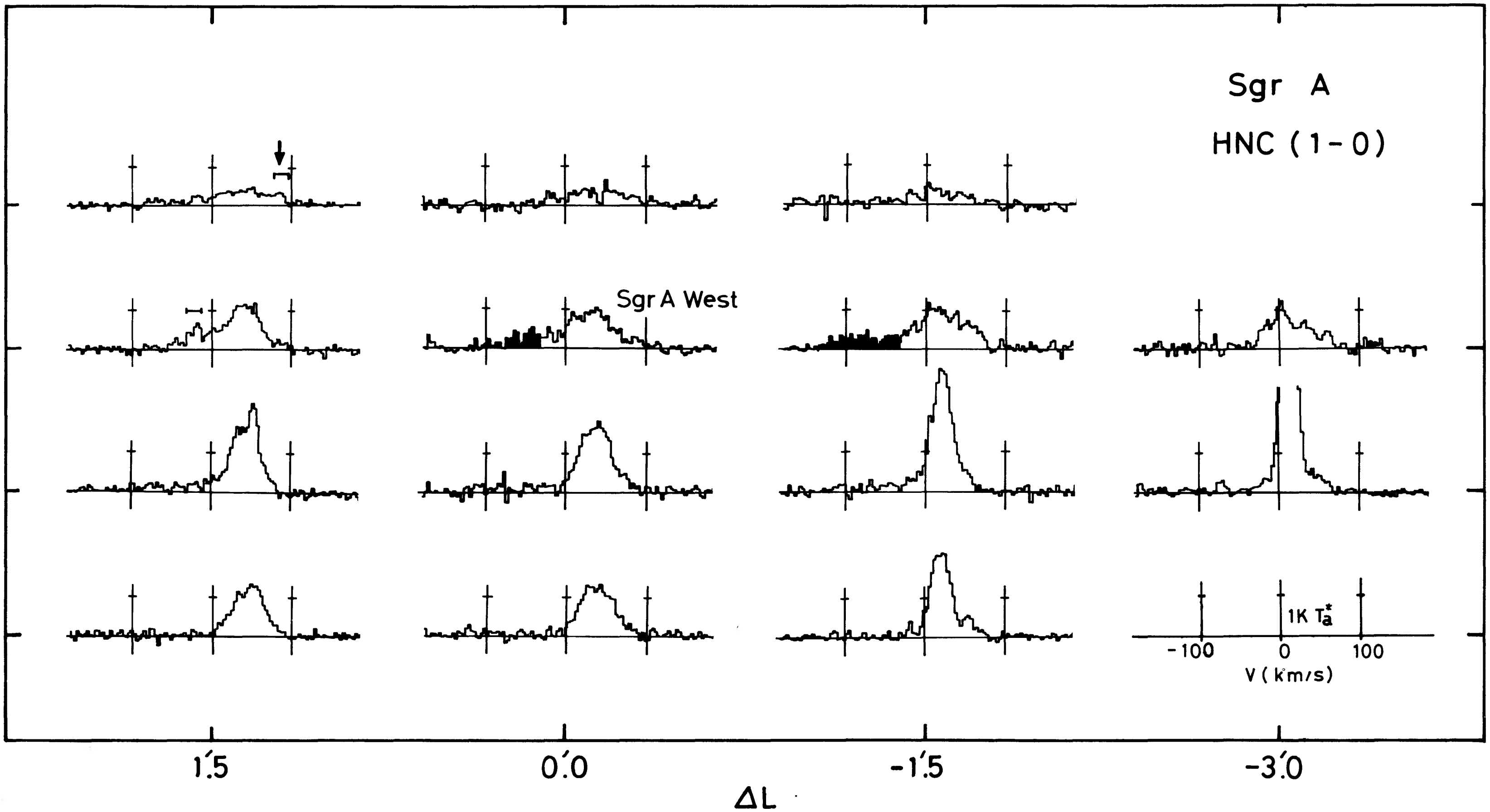

FIG. 2.—HNC profile map in the vicinity of Sgr A West. The negative velocity emission from -30 km s^{-1} to -140 km s^{-1}, which is shown by black areas at (0, 0) and (-1.5, 0), is obviously localized within a few arc minutes of Sgr A West. The profiles at $\Delta b = -3'$ demonstrate the baseline flatness typical of the present data. The integration time of the spectrum at Sgr A West is about one-sixth of that in Fig. 1. Each spectrum is not smoothed. The positive velocity emission at ≥ 80 km s^{-1} is indicated by an arrow at (1.5, 1.5). The narrow peak at (1.5, 0) marked by ⊢⊣ indicates a different component unrelated to the negative velocity emission (see Fukui *et al.* 1984).

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$\times 10^{22}$ cm^{-2}. The column density implies a visual extinction of $\gtrsim 15$ mag. The high velocity up to approximately -140 km s^{-1} and the concentration of the negative velocity gas within several parsecs of Sgr A West imply that the gas lies close to the galactic center, probably within the radius of several parsecs. We note that a small amount of dust grains ($A_v \gtrsim 1$ mag) is sufficient for protecting molecules against the ultraviolet radiation even in a case when the ultraviolet flux is increased by an order of magnitude over the general interstellar value as shown in the numerical simulation by Mitchell *et al.* The large visual extinction of approximately 15 mag is more than sufficient to protect the molecule.

It has been shown that there is only a small amount of visual extinction in the central parsec of the Galaxy mainly from near-infrared studies (e.g., Becklin *et al.* 1978; Becklin, Gatley, and Werner 1982). Thus it appears likely that the negative velocity gas lies at radii of 1–10 pc from the galactic center. When we compare the HNC data with the absorption-line data of H I (Sanders, Wrixon, and Mebold 1977) and H_2CO (Güsten and Downes 1981), we see, in between discrete narrow absorptions due to arms, rather continuous absorption which covers the velocity range of the negative velocity emission. Thus, we infer that at least part of the negative velocity gas lies in front of the galactic center, keeping in mind the ambiguity in the above comparison which results from different beam sizes (H I: 10′; H_2CO: 3′). Because the velocity width and distribution of the HNC negative velocity gas are considerably different from those of the [O I] gas, it is at present not clear how one can relate the two features.

b) *Kinematics of the Negative Velocity Gas*

The negative velocity emission in the negative galactic longitude is generally allowed in the galactic rotation, and it is possible to interpret the kinematics in terms of rotation around the galactic center. Then, the rotation period is estimated as approximately 2×10^5 yr at $r \sim 5$ pc. By assuming an equilibrium rotation, we find the mass within 5 pc of the galactic center to be approximately 2×10^7 $M_\odot$. This agrees with that derived from H I data by Oort (1977), but the agreement may be fortuitous as argued below.

There are some points which are not favorable to the rotational model. There is no definite counterpart on the diametrically opposite side of the galactic center, which is naturally expected when the gas forms a rotating disk around the galactic center. The following points suggest that the motion of the negative velocity gas cannot be explained solely by rotation; (1) there are some indications of the negative velocity emission in the positive galactic longitude which is not expected from a purely rotational motion; and (2) the winglike shape of the emission is unusual for rotation.

An alternative model for the negative velocity gas is a radial motion into or out of the galactic center. Because at least part of the gas is probably located in front of the galactic center, the negative velocity may mean expansion from the center. If such an outflow is the case, the process must have occurred very recently, i.e., $\lesssim 5 \times 10^4$ yr. The kinetic energy and the mass flow rate are, then, estimated to be $\gtrsim 1.5 \times 10^{51}$ ergs and $\gtrsim 0.3$ $M_\odot$ yr^{-1} respectively. The energy may be barely supplied by a supernova explosion in the galactic nucleus. Alternatively, some active events in the galactic nucleus may be responsible for it. On the other hand, if an inflow is the case, the gas may have been stripped off from the Sgr A molecular cloud by tidal force. Obviously, a more detailed modeling of the negative velocity gas must await observations of higher spatial resolutions.

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