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HIGH-VELOCITY FORMALDEHYDE ABSORPTION WITHIN 30″ OF THE GALACTIC NUCLEUS

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ABSTRACT

We report VLA observations of the $(1_{10}\text{–}1_{11})$ line of H_2CO in absorption within 30″ of the Galactic center point source Sagittarius A* (Sgr A*) with a resolution of 20″.6 × 9″.5 at P.A. = 4°, and an rms noise of 3.5 m Jy beam^{-1}. The absorption peaks within 15″ of Sgr A*, and extends in velocity from about +135 km s^{-1} to at least −210 km s^{-1} (with some interruptions). We performed a number of baseline subtractions using different velocity intervals to define the continuum level. In all cases the absorption is definitely present. At positions offset ±1′ in latitude from Sgr A* there is no evidence for absorption at high velocities. Thus, the high-velocity gas may be close to, but is not coincident with, Sgr A*. The gas with velocities between −157 and −205 km s^{-1} is located east and northeast of the continuum peak, and gas at about +135 km s^{-1} is also located to the east. The position of the absorption relative to the continuum leads us to believe that the negative velocity molecular gas is behind Sgr A*. Because the gas is localized near Sgr A*, we do not think that there is any interaction with Sgr A East.

Taken together with observations of HCO^+, HCN, and [O I], there are now several lines of evidence which indicate that the central cavity at the Galactic center contains a mixture of neutral and ionized gas.

Subject headings: Galaxy: center — galaxies: nuclei — ISM: molecules

1. INTRODUCTION

The region within a radius of 30″ of the Galactic nucleus contains neutral and ionized gas clouds, stars and star clusters, magnetic fields, and a radio point source, Sgr A*, believed to be the dynamical center of the Galaxy (cf. Genzel & Townes 1987, Morris 1989, and references therein). At larger radii, $r \sim 2'\text{–}3'$, the radio radiation from the Galactic center shows an extended region of nonthermal emission called Sgr A East, and a somewhat more compact source of thermal emission, Sgr A West. The region around Sgr A*, described above, is associated with Sgr A West. We follow Pedlar et al. (1989) in placing Sgr A East, thought to be a supernova remnant, behind Sgr A West. Spectroscopic studies at radio and infrared wavelengths of the gas kinematics reveal large-scale systematic motions with velocities, both positive and negative, up to several hundred km s^{-1}. The ionized gas, studied via continuum radiation and emission lines of H^+ (Roberts et al. 1991) and Ne^+ (Lacy, Achterman, & Serabyn 1991) at 1″–2″ resolution, is concentrated in a spiral-like, filamentary structure centered on Sgr A* (Lo & Claussen 1983). Lacy et al. have modeled the kinematics of the ionized gas using approximately circular orbits with a nearly Keplerian rotation curve which requires a central point mass of $2 \times 10^6\ M_\odot$. It is generally thought that within ≤1.5 pc (about 40″ if $R_0 = 8.5$ kpc) there is a cavity filled primarily with ionized gas. However, recent observations of the [O I] 63 μm line show that neutral *atomic* gas is present in the central cavity (Jackson et al. 1993). The molecular gas is thought to lie primarily outside the cavity and appears to deliniate a clumpy ring or disk with an inner radius of ∼1.5 pc and a rotational velocity of about 100 km s^{-1} (Güsten et al. 1987).

In spite of all these data, until recently, the question of outflow versus inflow of molecular gas toward Sgr A* was still open. Zylka, Mezger, & Wink (1990) and Ho et al. (1991) have argued from 10″ and 12″ maps that molecular gas *must* be flowing toward Sgr A*. However, large negative velocity gas *is* found in absorption against the continuum. The most notable example is the absorption of H_2CO between −160 and −200 km s^{-1} at 4.8 GHz observed by Güsten & Downes (1981) with 3′ resolution. They concluded that this gas may have been ejected from the nucleus.

In this *Letter* we present new VLA observations of H_2CO absorption made with a resolution of 20″.6 × 9″.5. Our data give the location of the H_2CO absorbing gas relative to the radio continuum from the ionized gas.

2. OBSERVATIONAL PARAMETERS AND DATA REDUCTION

The Galactic center was observed on 1988 August 19 with the D configuration of the NRAO[5] VLA for a 7 hr period at the frequency of the $H_2CO(1_{10}\text{–}1_{11})$ transition, 4.82966 GHz. The spectrometer bandwidth was 6.25 MHz, divided over 128 channels, giving a velocity resolution of 3 km s^{-1} (no Hanning smoothing), and a velocity coverage from −230 to +150 km s^{-1}. Observations of 3C 286 (7.46 Jy at 4.8 GHz) were used to calibrate the spectrometer bandpass and set the flux density scale, and NRAO 530 was used for phase calibration. All data reduction and analysis was done using the Astronomical Image Processing System (AIPS). The continuum level was established by using the emission between −70 and −100 km s^{-1} and between +102 and +121 km s^{-1}. After calibration, and bandpass correction, the continuum emission was subtracted from the *u-v* data base using the task UVBAS (van Langevelde & Cotton 1990). The resulting line-minus-continuum *u-v* data were edited, mapped onto a 256 × 256 grid with a 3″ × 3″ pixel size using uniform weighting, and deconvolved,

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yielding a synthesized beam of 20″.6 × 9″.5 at P.A. = 4°, and a final rms noise on the individual channel maps of about 3.5 mJy beam^{-1}.

3. RESULTS AND DISCUSSION

3.1. *Comparison with the Single-Dish Spectrum*

Figure 1 shows a comparison between the single-dish H_2CO absorption spectrum made by Güsten & Downes with 3′ resolution and our VLA data averaged over 15″ × 15″, both centered on Sgr A*. In this *Letter* we will discuss high-velocity absorption confined within ±30″ of Sgr A*. Inspection of Figure 1 shows that there is absorption from +135 km s^{-1} to beyond −210 km s^{-1}, with some interruptions, and is nearly continuous from −120 km s^{-1} to about −210 km s^{-1}, where we have cut off the plot because of the increased noise near the edge of the spectrometer bandpass. The H_2CO spectrum of Güsten & Downes shows absorption between −70 and −100 km s^{-1} which is not present in our spectrum. We used data in this velocity range and at velocities between +102 and +121 km s^{-1} to determine the continuum level in our data, and, thus the absolute value of the absorption line we observe may be underestimated. In order to test the sensitivity of the positions of the absorption features to the choice of continuum channels, we have reanalyzed our data using only channels between +102 and +139 km s^{-1} to define the continuum level. These tests show that the absorption peaks shift by 1–3 pixels, and we conclude that the positions of the absorption features should be accurate to about 10″. In addition, the absorption may extend over more than the ~350 km s^{-1} presented here, as is suggested by the line shape seen in Figure 1.

From Figure 2 (Plate L1), a longitude-velocity diagram of H_2CO absorption made at the latitude of Sgr A*, we see that there is extensive absorption within ±30″ of Sgr A*. Similar longitude-velocity diagrams made at latitudes offset ±1′ from the latitude of Sgr A* show no high-velocity absorption. However, assuming all the continuum is behind the molecular clouds, it is possible that formaldehyde is present at these velocities but is not detected due to the lower continuum levels at the offset positions. Figures 1 and 2 suggest that the H_2CO clouds have a fairly clumpy distribution, with several narrow peaks of increased absorption superposed on broader, weak absorption. Some of the peaks are associated with well-known features seen along the line of sight to the Galactic center such as the "3 kpc arm" at −50 km s^{-1}, and the "expanding molecular ring" at −135 km s^{-1}, which is located about 200 pc from the Galactic center. The absorption which peaks at around +90 km s^{-1} is seen in OH (Sandqvist et al. 1987) and HCN (Güsten et al. 1987) at the position of the circumnuclear ring. Although Whiteoak, Gardner, & Pankonin (1983) have published maps of Sgr A in the 4.8 GHz H_2CO line, features at −170 to −200 km s^{-1} were not detected because of the lower sensitivity of those observations. We identify the weak, broad absorption at negative velocities with the "high-velocity gas" seen by Güsten & Downes (1981).

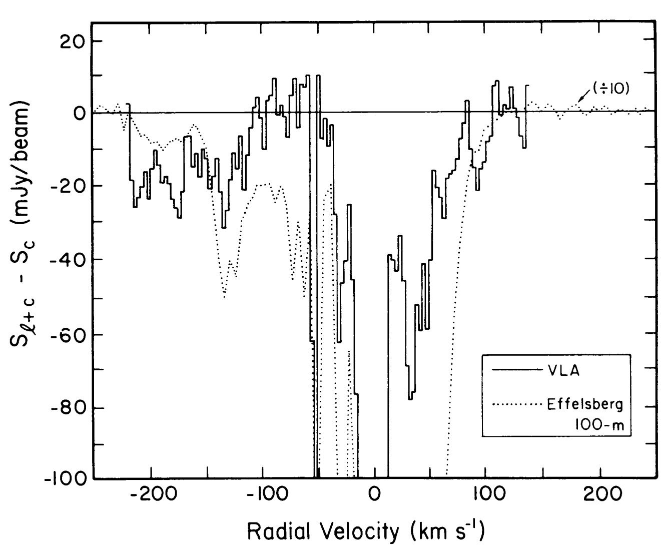

FIG. 1.—Composite H_2CO absorption spectrum showing the single-dish data from Güsten & Downes (1981) in a 3′ beam (*dotted line*) divided by 10 and our data averaged over a 15″ × 15″ region, both centered on Sgr A*. Note that there are many points at which the spectra do not agree. This is especially true in the −50 to −130 km s^{-1} range.

3.2. *The Location of the Absorbing Gas*

In Figure 3 we plot absorption maps of the negative velocity channels from −167 to −213 km s^{-1}. Figures 2 and 3 show that the peaks of the high-velocity gas lie within about ±15″ of Sgr A*. The blueshifted clouds are primarily located east and northeast of the nucleus, although there is gas to the west at −172 km s^{-1} and weaker absorption about 25″ southwest of Sgr A* between −185 and −192 km s^{-1}. The redshifted gas at +135 km s^{-1} also peaks to the east. *In no case does the maximum absorption appear to be coincident with Sgr A**. We note that most of the peaks in Figure 3 are unresolved in our 20″.6 × 9″.5 beam.

In order to investigate the relationship between the neutral gas, traced by the H_2CO, and the ionized gas in the nucleus, we have made the composite maps in Figure 4 (Plate L2). Here the H_2CO absorption is displayed as a gray-scale image superposed on contours of our 4.8 GHz continuum, which includes emission from the ionized filaments smoothed by our beam. Within the limits imposed by the spatial resolution of the present observations, we feel Figure 4 suggests that the neutral gas may lie between the ionized filaments, but this suggestion needs to be verified by observations with higher spatial resolution. Assuming that all the continuum is behind the H_2CO clouds, we derive apparent optical depths, $\tau \sim 0.01$–0.02, which implies $A_v \sim 1$–2 mag. Thus, the actual optical depths may be larger. If T_{ex} is constant, then our absorption maps also trace column density.

Figures 3 and 4 show that the maximum H_2CO absorption occurs at projected distances as close as 15″–20″ from Sgr A*. We feel that the small projected distance and the high radial velocity strongly suggest that the neutral gas traced by H_2CO is near the Galactic nucleus, well within the 10 pc lower limit set by Güsten & Downes (1981). In fact, it may well be that the projected and true distances are very nearly the same. For example, if the gas originates in the circumnuclear disk with a rotational velocity of ~110 km s^{-1} at about 1.5 pc from the center and falls in the gravitational field of a $4 \times 10^6\ M_\odot$ point mass, it will reach a rotational velocity of ~200 km s^{-1} at a distance of 0.6 pc from the nucleus. Since the observed velocity is only the radial component of the total velocity, this gas is probably closer than 0.6 pc from Sgr A*.

However, Figure 3 shows that none of the H_2CO absorption maxima peak at the position of Sgr A*. The maximum in the HCO^+ absorption at large negative velocities reported by Marr et al. (1992) is offset to the southwest and west of Sgr A*, and an H I spectrum with 3″ resolution toward Sgr A* shows

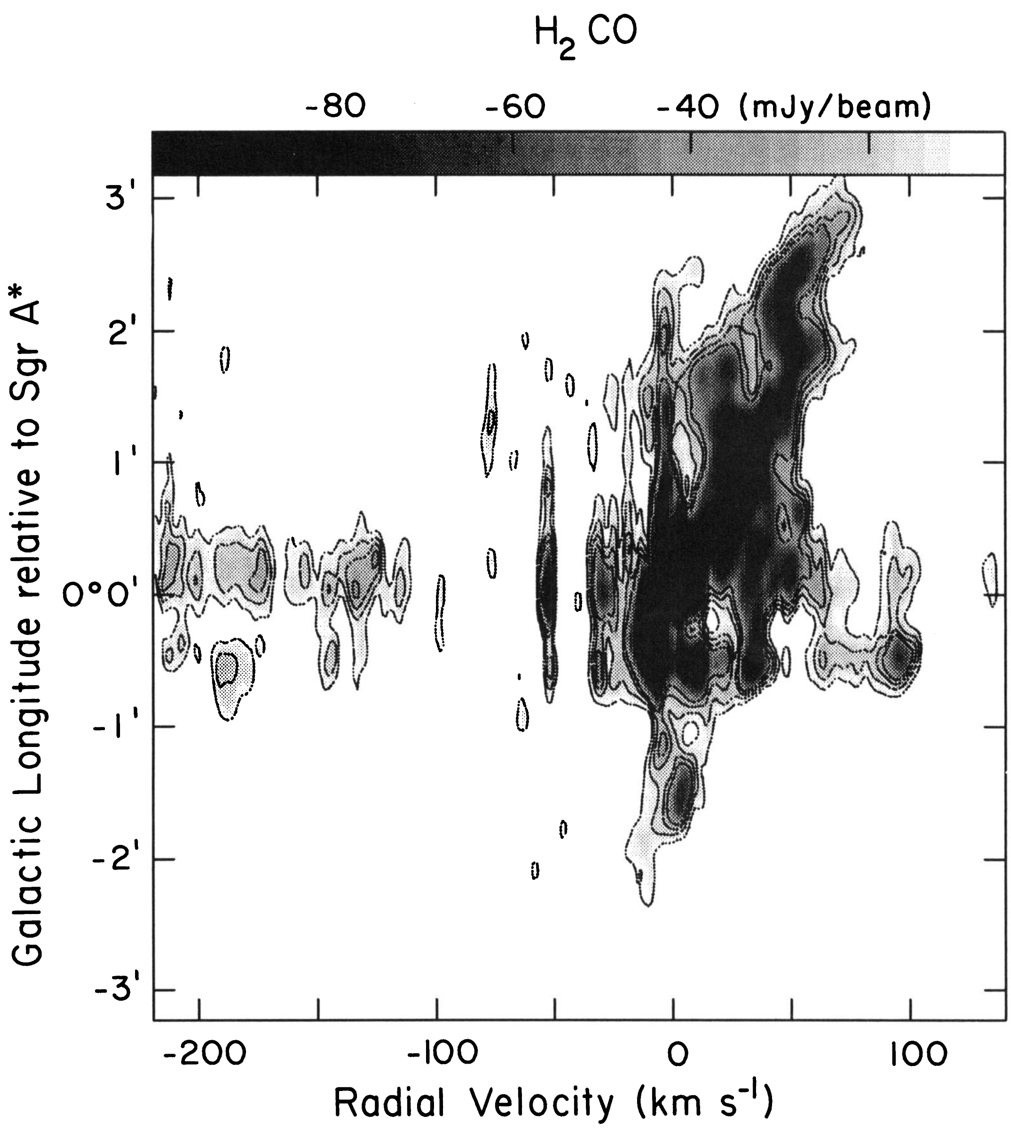

FIG. 2.—Longitude-velocity diagram of H_2CO absorption at the latitude of Sgr A* ($b = -2.75$). Contour levels are -10, -20, -30, and -40 mJy beam^{-1}. Note the weak, high-velocity absorption appears to be confined within about $\pm 30''$ of Sgr A*. There appear to be two sets of extended, high-velocity absorption features located on either side of $\Delta l = 0$.

PAULS et al. (see 403, L14)

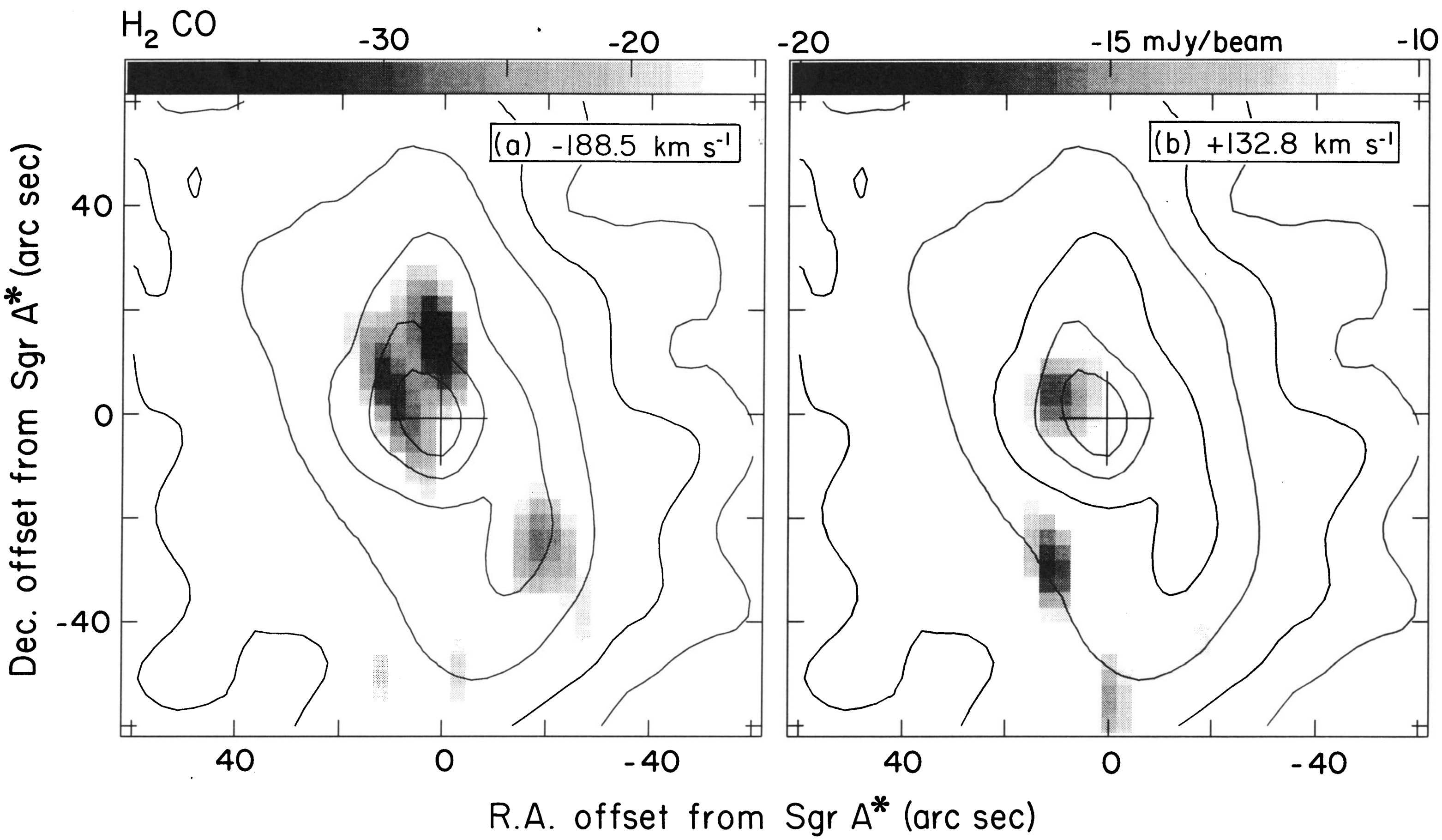

FIG. 4.—(*a*) A composite figure showing the H_2CO absorption at -188.5 km s^{-1} superposed on the 4.8 GHz continuum from Sgr A. The position of Sgr A* is marked by a cross. The contour levels for the continuum are 5, 10, 20, 40, 60, and 80% of the peak flux of 4.07 Jy beam^{-1}. The gray scale at the top of each plot shows the absorption in mJy beam^{-1}. (*b*) The H_2CO absorption at $+132.8$ km s^{-1}.

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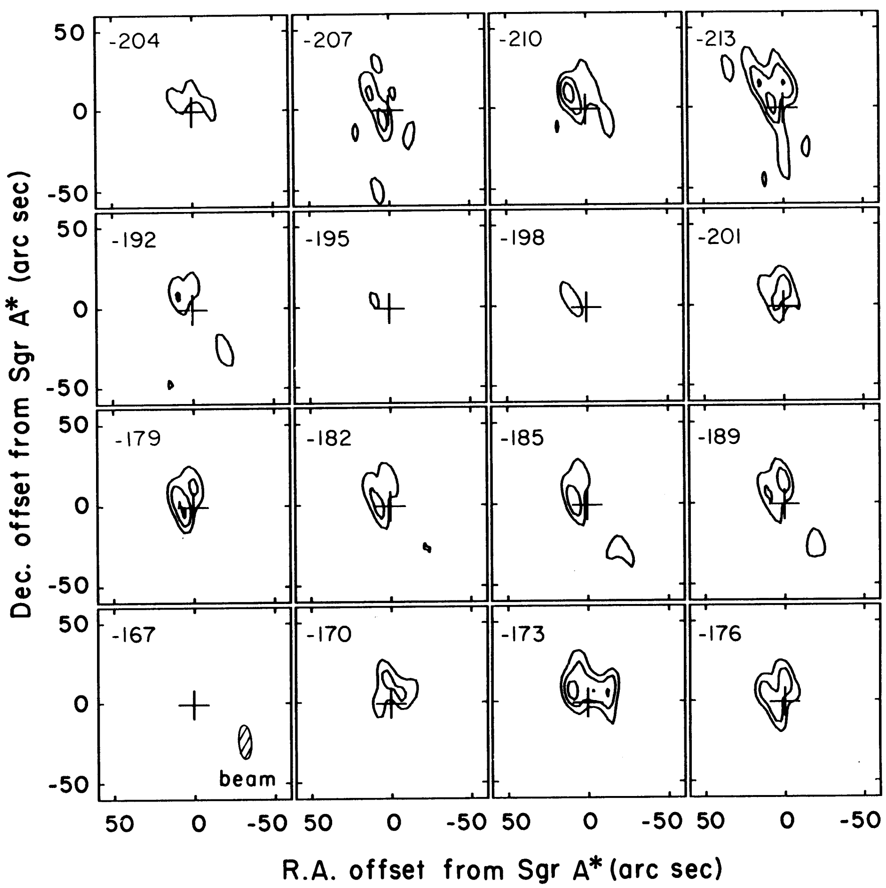

FIG. 3.—Individual channel maps of H_2CO absorption for velocities from −167 to −213 km s^{-1}. Note that the absorption is located primarily east and northeast of Sgr A* (denoted by the cross). The synthesized beam is shown as an ellipse in the channel at −167 km s^{-1}. Contour levels are −20, −30, and −40 mJy $beam^{-1}$.

no absorption at velocities beyond −150 km s^{-1} (Liszt, Burton, & van der Hulst 1985). All these data suggest that high-velocity neutral gas lies close to the position of Sgr A* but is not coincident with it.

If the nonthermal source Sgr A East lies behind Sgr A West (Pedlar et al. 1989), and Sgr A* is close to Sgr A West, then the neutral gas we observe may be between Sgr A East and Sgr A West. Additionally, if Sgr A East is a supernova remnant (SNR), then the high negative radial velocities might be caused by molecular gas in front of Sgr A East, pushed in our direction by the SNR shell. In this case there might be little or no connection with Sgr A*. However, our *l-v* diagrams at latitude offsets of ±1′ from Sgr A* show no evidence of high negative velocity gas. We feel, therefore, that the blueshifts may arise near Sgr A*.

4. CONCLUDING REMARKS

There are now several independent lines of evidence which indicated that neutral gas may be mixed with ionized gas within 0.5 pc of the Galactic nucleus. The neutral gas has now been detected in H_2CO (this paper), HCO^+ (Marr et al. 1992), and HCN and [O I] (Jackson et al. 1993); and there is now strong evidence that massive star formation has occurred in the central parsec within the last few million years (Krabbe et al. 1991), producing a cluster of young, hot stars. In addition, recent infrared polarimetry observations at 12.4 μm demand the presence of dust grains in this region as well (Aitken et al. 1991). If the dust provides the shielding so that photodissociation regions form (Tielens & Hollenbach 1985), our results support the suggestion that the northern and eastern arms of the ionized filaments may be bright ionized rims on the surface of the neutral gas clouds (Jackson et al. 1993).

Our data are consistent with a mass within 0.4 pc of 3×10^6 $M_\odot$, derived from other tracers, but do *not* in any way place a limit on the central mass of Sgr A. These results show that the main objections to infall are no longer valid: the *negative velocity* gas seems to be behind Sgr A*. However, any infall model must satisfy rather complex kinematic conditions.

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