HI Absorption Against the 40 km s^{-1} Cloud and the Circum-Nuclear Disk in Sgr A

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Abstract: HI absorption studies of the Sgr A complex based upon recent VLA[2] observations, show that the 40 km s^{-1} molecular cloud lies *behind* the Sgr A West region, and that the cloud may be physically associated with the Sgr A East non-thermal shell. The absorbing gas over the range +30 to +60 km s^{-1} lies mainly between the eastern edge of the Sgr A East shell and the western boundary of a cluster of HII regions. There is a pronounced velocity gradient over this region, and at 40 km s^{-1} similar morphology is apparent between the distribution of atomic hydrogen and the edge of the Sgr A East shell. The physical association of the 40 km s^{-1} cloud and the Sgr A East shell, and the placing of the 40 km s^{-1} cloud behind Sgr A West, are consistent with recent evidence which has demonstrated that Sgr A West lies *in front* of Sgr A East. The HI optical depth maps of the circum-nuclear disk plus a new HI feature associated with the northern extension of Sgr A West will be presented.

Introduction

Radio continuum emission from the inner 7′ of the Galactic Center region indicates that the bright core of the Sgr A complex consists of three prominent components: Sgr A East, a nonthermal shell-like structure which is elongated along the Galactic plane; Sgr A West, a thermal feature which lies at the southwestern perimeter of Sgr A East and is centered about the dynamical center of the Galaxy; and an elliptical halo which closely delineates and appears to be associated with the outer portion of the Sgr A East shell (Ekers *et al.* 1983; Yusef-Zadeh and Morris 1987, [hereafter YM87]). Recent 327MHz radio continuum images have demonstrated with near certainty that Sgr A West lies in front of Sgr A East (YM87; Pedlar *et al.* 1988), thus supporting the earlier picture inferred from molecular line observations (Güsten *et al.* 1981; Whiteoak *et al.* 1974). The relative placement of the prominent 40 km s^{-1} molecular cloud with respect to Sgr A East and Sgr A West has been discussed by numerous authors, but universal agreement on the true geometry of this cloud is far from being reached (see Brown and Liszt 1984). Here, we present the results of HI absorption observations toward the Sgr A complex and demonstrate that the 40 km s^{-1} cloud is physically associated with Sgr A East, and that it appears to lie behind Sgr A West. This interpretation is consistent with a number of previous absorption studies which also suggest placing Sgr A East behind Sgr A West (Sandqvist 1974; Whiteoak *et al.* 1974; Schwarz *et al.* 1977).

Observations and Results

The HI absorption observations toward the radio continuum Arc and the Sgr A complex were carried out with the VLA in its hybrid C/D configuration. A detailed description of these observations is given elsewhere (Lasenby *et al.* 1988). Here, we report some preliminary results concerning HI absorption toward the Sgr A complex. The maps presented have $\sim 53'' \times 40''$ spatial and 10.2 km s^{-1} velocity resolution. The HI absorption measurements discussed below differ in two im-

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portant respects from previous interferometric measurements: firstly, they have greater sensitivity to large-scale structures; and secondly, the construction of the optical depth maps is based on a new statistical technique (see Lasenby *et al.* 1988) which results in more accurate and reliable values.

The Morphology and Kinematics of the $40\,km\,s^{-1}$ *Cloud*: Figures 1a & 1b show the greyscale distribution of HI optical depth toward the Sgr A complex superimposed on contours of continuum emission at λ21cm and on contours of HI optical depth, respectively. The continuum contour map (which has *not* been corrected for primary beam attenuation) is made from averaging the outer channels of the 3.125MHz bandwidth ($\equiv 660\,\mathrm{km\,s^{-1}}$), where no HI absorption was detected. The optical depth distribution is constructed by integrating over three velocity channels between 35 and $65\,\mathrm{km\,s^{-1}}$. We see that the bulk of the HI gas in this velocity interval is concentrated to the east of the Sgr A complex, and that there is a marked absence of HI absorption toward Sgr A West. The question of whether this lack of absorption is due to the position of Sgr A West or to a rapid decrease in column density of the cloud towards Sgr A West is discussed shortly. We estimate a column density for H_2 in the Sgr A East region, over this velocity interval, of $N(H_2) \sim 6.9 \times 10^{22}\mathrm{cm^{-2}}$. This distribution of neutral gas is consistent with previous HI absorption measurements (Sandqvist 1974; Schwarz *et al.* 1977; Liszt *et al.* 1983). One of the most interesting results of this study is that the HI gas with the largest column density lies to the eastern edge of Sgr A East, where a gap is seen in the shell (YM87) and that the morphology of the HI distribution is very similar to the shell-like geometry of Sgr A East. Okumura-Kawabe *et al.* (1988) have similarly found that the intense NH_3 emission from the $40\,\mathrm{km\,s^{-1}}$ cloud is confined to the region to the east of Sgr A East. Mezger *et al.* (1988) have also reported the detection of dust emission from a ring surrounding Sgr A East, and one finds that the northeastern portion of their λ1.3mm map coincides with the distribution of HI gas. These characteristics suggest strongly that the $40\,\mathrm{km\,s^{-1}}$ neutral gas is coupled to the Sgr A East nonthermal source.

For the material between 35 and $65\,\mathrm{km\,s^{-1}}$ we can estimate a value for the H_2 column density of $N(H_2) \sim 4.4\times10^{22}\mathrm{cm^{-2}}$ based on ^{12}CO and ^{13}CO maps in roughly the same velocity interval published by Liszt *et al.* (1985) and Bally *et al.* (1987), respectively. This value implies that in the direction of Sgr A West we should find $\tau \gtrsim 2.4$, which is roughly 6 to 7 times higher than we see in Figure 1a. Thus, we must infer that the $40\,\mathrm{km\,s^{-1}}$ cloud lies **behind** Sgr A West. This conclusion is in agreement with that of Geballe (1988) who bases his discussion on CO absorption spectra taken at 4.6μm toward IR sources known to lie near the Galactic Center. It has been suggested by some authors that the $40\,\mathrm{km\,s^{-1}}$ material seen toward Sgr A West is not part of the $40\,\mathrm{km\,s^{-1}}$ cloud because the velocity gradients seen toward Sgr A West are larger than those observed in the $40\,\mathrm{km\,s^{-1}}$ cloud. We will see shortly, however, that across Sgr A East the $40\,\mathrm{km\,s^{-1}}$ cloud displays a considerable velocity gradient, and therefore, there is no reason to believe that the material we see toward Sgr A West is not also part of this cloud.

One can also argue for such a placement of the $40\,\mathrm{km\,s^{-1}}$ cloud from the previously inferred physical association between Sgr A East and this cloud. Since there appears to be direct evidence from 327-MHz continuum observations that Sgr A East lies behind Sgr A West (YM87, Pedlar *et al.* 1988), then if the $40\,\mathrm{km\,s^{-1}}$ cloud *is* physically associated with Sgr A East, it must naturally lie behind Sgr A West.

Individual channel maps of the HI optical depth distribution for velocities from 60 to $30\,\mathrm{km\,s^{-1}}$, as seen in Figure 1(c-f), indicate a decrease in velocity as we move due south along the boundary of the Sgr A East shell. The semi-circular pattern of the HI optical depth distribution surrounding Sgr A East is best seen in Figure 1d at a velocity of $\sim 50\,\mathrm{km\,s^{-1}}$. The declination-velocity diagram presented in Figure 2, taken through RA=$17^h42^m38.8^s$, shows a continuous velocity structure be-

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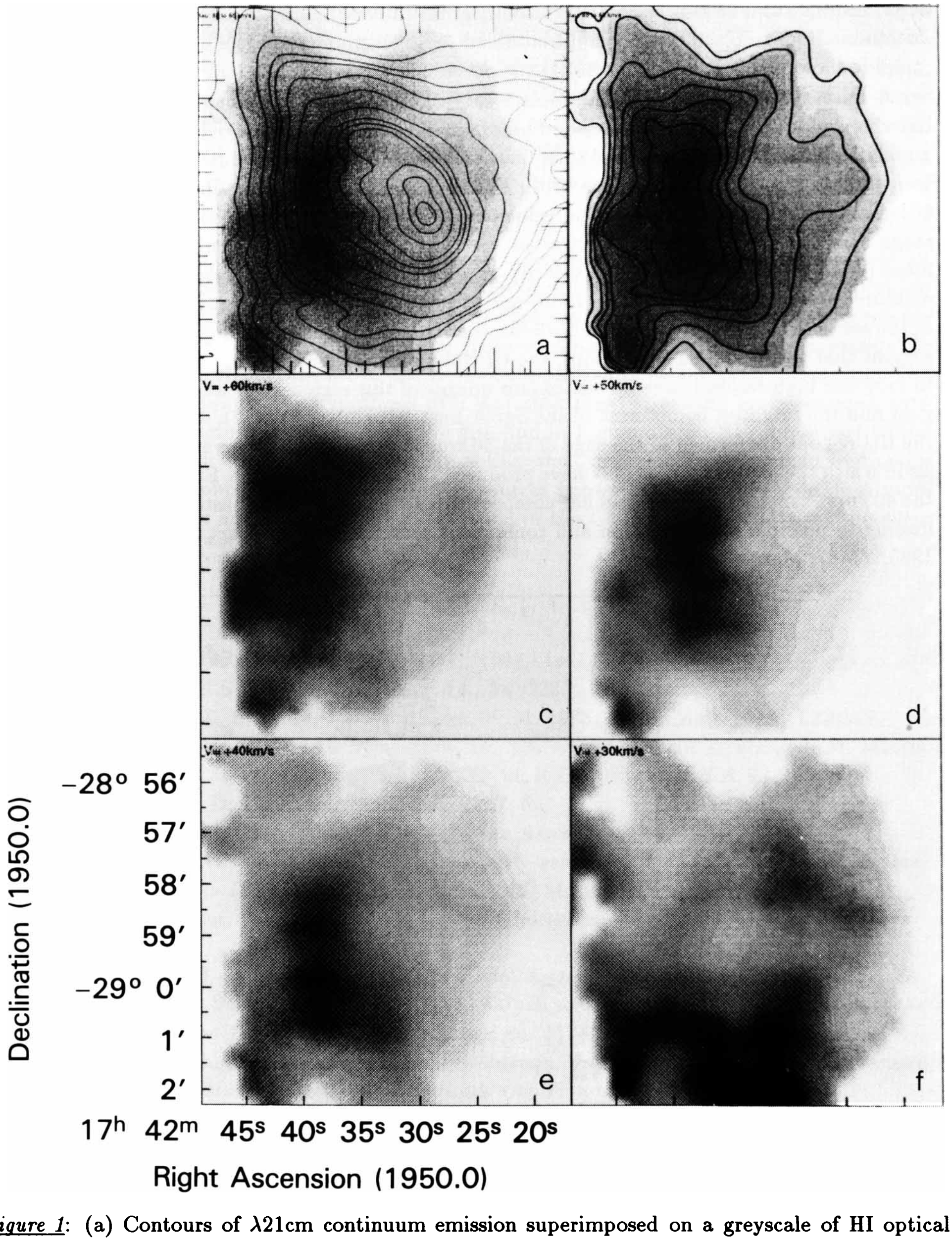

Figure 1: (a) Contours of λ21cm continuum emission superimposed on a greyscale of HI optical depth (τ) integrated between 35 to 65 km s^{-1}. The scale on the τ map is linear and ranges from 0(white) to 3.79 km s^{-1}(black). Levels are 0.5, 0.7, 1.0, 1.3, 1.5, 2, 3, 5, 7, 8, 9, 11, 13, 14 Jy/beam (b) Contours of τ superimposed on the greyscale shown in Figure (1a). Levels are 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.8, 2.0, 2.2, 2.5, 3.0, 3.5, 3.6, 3.7 km s^{-1}. (c-f) Individual channel maps of τ between 60 to 30 km s^{-1}. All scales are linear and range from: c) 0 to 1.18 km s^{-1}, d) 0 to 1.79 km s^{-1}, e) 0 to 1.84 km s^{-1}, f) 0 to 1.08 km s^{-1}.

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tween about 25 and 85 $\mathrm{km\,s^{-1}}$ having a velocity gradient of $\sim$ 15 $\mathrm{km\,s^{-1}}$ $\mathrm{arcmin^{-1}}$ in the north-south direction . High-resolution radio continuum and radio recombination line observations of the Sgr A complex show a cluster of compact HII regions which appear to lie along the eastern edge of the Sgr A East shell (Ekers *et al.* 1983; Goss *et al.* 1985). Because of the small angular scale of this HII cluster ($\sim$ 30″) compared with our beam, its flux density is diluted by background radiation associated with the Sgr A halo and thus the HII cluster is not brought out in the λ21cm continuum map (Figure 1a). The western edge of the Sgr A East HII cluster lies adjacent to an HI clump at 40 $\mathrm{km\,s^{-1}}$, as seen in Figure 1e. The velocities of the ionized gas associated with the HII cluster range between 43 and 51 $\mathrm{km\,s^{-1}}$ in a sense which is opposite to that seen in the HI optical depth maps (Goss *et al.* 1985), while the velocity gradient in the 40 $\mathrm{km\,s^{-1}}$ cloud on larger scales ($\sim$ 6′) measured by Güsten and Downes (1980) agrees in sense with our HI data. Despite the difference in the sense of the velocity gradient between the HI and HII gas, their morphology and kinematics suggest that the cluster of HII regions, the HI cloud and Sgr A East are part of a unified structure. In fact, the high-resolution radio continuum images of this region show a clear link between Sgr A East and the brightest component of the Sgr A East HII cluster (YM87), supporting the view that the HII regions are formed at the edge of the 40 $\mathrm{km\,s^{-1}}$ cloud. Such observations suggest a hypothesis in which the explosion that may have produced the nonthermal Sgr A East shell, occurred inside the 40 $\mathrm{km\,s^{-1}}$ molecular cloud and has compressed and accelerated the eastern segment of the cloud leading to possible star formation and consequent production of compact HII regions (Goss *et al.* 1985; YM87; Mezger *et al.* 1988).

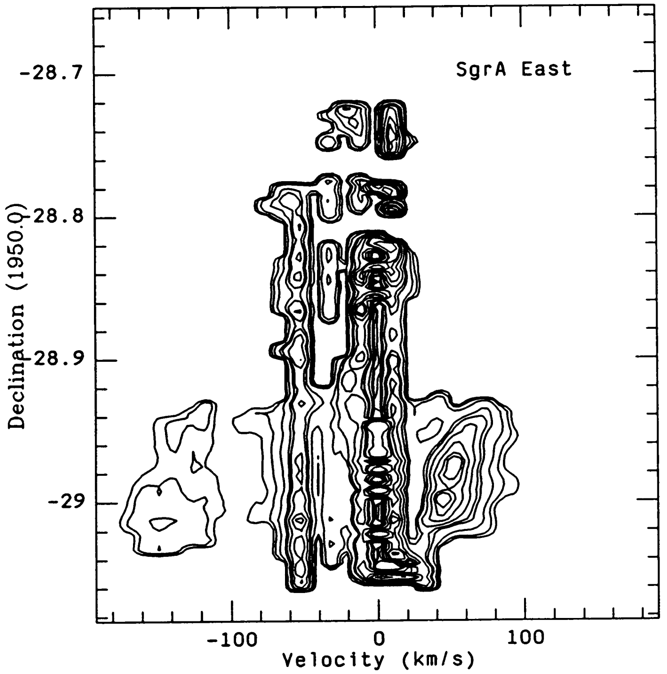

Figure 2: Declination-velocity plot of HI optical depth cut through at RA= $17^h\ 42^m\ 38.8^s$. Contour levels are 0.05, 0.1, 0.2, 0.4, 0.5, 0.7, 1.0, 1.3, 1.5, 2.0 $\mathrm{km\,s^{-1}}$.

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The HI Distribution in the Circum-Nuclear Disk (CND): Figure 3a shows the HI optical depth map constructed by integrating over the velocity range, $75 \lesssim |v| \lesssim 130\,\mathrm{km\,s^{-1}}$, superimposed on the distribution of CO J=1 $\rightarrow$ 0 emission integrated over a similar velocity range of $80 \lesssim |v| \lesssim 110\,\mathrm{km\,s^{-1}}$ (Serabyn *et al.* 1986). We see from this figure that the overall morphology of HI gas in the CND correlates extremely well with the distribution of CO gas. A 30″ displacement between the HI and CO peaks in the lobes might be due to the different velocity ranges used in making the HI and CO maps. In the southern lobe of the CND we estimate an H_2 column density of $N(H_2) \sim 2.9 \times 10^{22}\mathrm{cm^{-2}}$ using the HI measurements.

Figure 3b shows the optical depth map over a larger area than seen in Figure 3a. We note an elongated feature immediately to the northwest of the northern lobe of the CND. The position angle of this feature is strikingly similar to that of the ionized streamers which appear to emerge from the northern arm of the Sgr A West spiral (referred to as the 'northwestern streamers' in YM87). Remarkably, the HI feature lies at the edge of the ionized streamer. The morphology and kinematics of the HI supports the hypothesis of YM87 that these streamers are associated with the three-arm spiral structure of Sgr A West. We also find in Figure 3b the HI counterpart to the eastern protrusions which appear to cross the Sgr A East shell in high-resolution radio continuum images (YM87), and a couple of discrete continuum sources known as I3 and H8 (YM87). A more detailed and quantitative account of the HI distribution in the CND and its vicinity will be given elsewhere.

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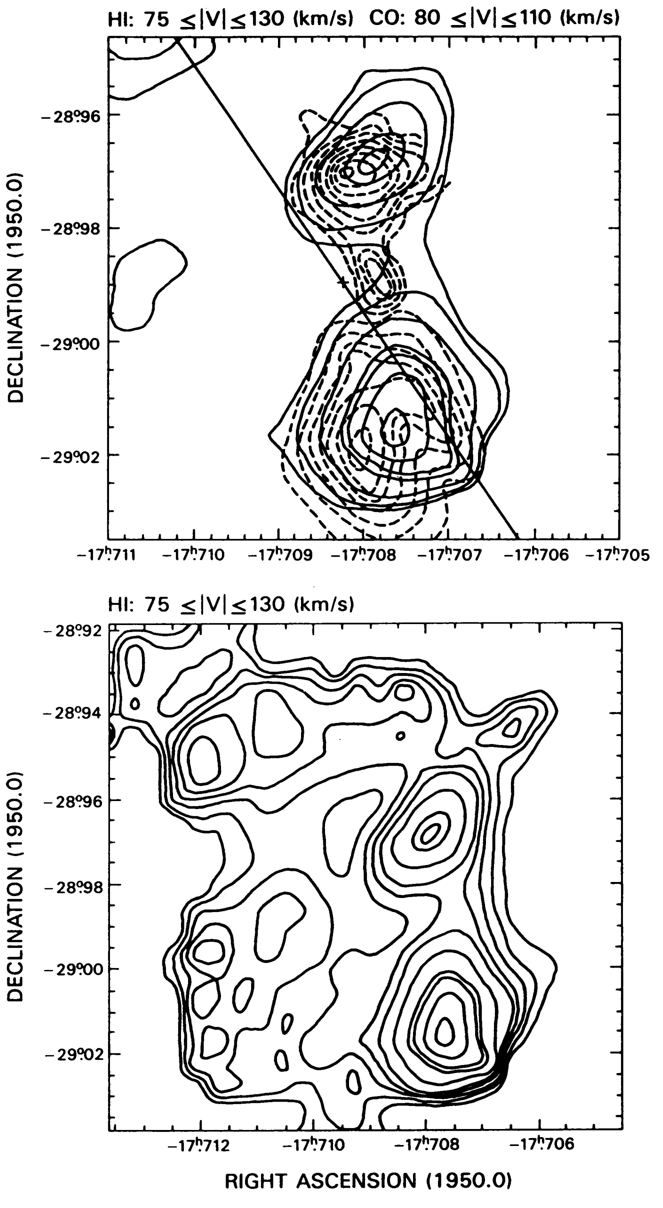

Figure 3:(a) [top] Solid contours of HI optical depth (τ) set at 0.4, 0.5, 0.7, 1, 1.3, 1.5 $\mathrm{km\,s^{-1}}$ superimposed on contours of CO map (dashed lines) by Serabyn *et al.* 1986. The velocity ranges chosen for HI and CO are indicated on top of each figure. (b) [bottom] The contour map of HI τ over a larger area than that shown in (a). Levels are 0.1, 0.2, 0.3, 0.4, 0.5, 1, 1.1, 1.3, 1.5 $\mathrm{km\,s^{-1}}$.