The Galactic Center 50-km s$^{-1}$ Molecular Cloud with An Expanding Shell

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Abstract

We performed high-resolution observation of the Galactic Center 50-km s$^{-1}$ molecular cloud in the CS $J = 1 - 0$ line using the Nobeyama Millimeter Array (NMA). The molecular cloud mainly has three different spatial components with large velocity widths up to 60 km s$^{-1}$. The northwest component is located at an apparent contact point to the Sgr A east shell and elongated along the boundary of the shell. The large velocity width of the component is responsible for the interaction with the Sgr A east shell. The molecular gas distribution in CS line emission is dissimilar to that observed previously in NH$_3$ line emissions. The appearances shows presumably the area of CS line emission enhanced by shock. The central and southwest components are located just out of the Sgr A east shell and far from it, respectively. However, these components have large velocity widths. We found a well-shaped circular molecular shell with expanding motion in the 50-km s$^{-1}$ molecular cloud. This is responsible for the large velocity width. The continuum source in the expanding molecular shell has a steep spectrum in the mm-wave although this is not identified in the previous 5-GHz map. This source may be an SNR with an ionized sheath. From the aspect ratio of the expanding molecular shell of 1.1, the magnetic field in/around the shell is estimated to be smaller than 100$\mu$ Gauss. The weak magnetic field is consistent with on-going active star formation in the 50-km s$^{-1}$ molecular cloud. The comparison among CS line emission, low frequency continuum, and millimeter continuum toward the 50-km s$^{-1}$ molecular cloud suggests a face-on view of the Sgr A region. The molecular cloud is located in the Sgr A halo region.

Key words: Galaxy, molecular cloud, super nova remnant
1. Introduction

The Galactic Center region is the nearest nucleus of a spiral galaxy. We can observe in detail unique features related to the star formation fed by infalling molecular clouds using present radio telescopes. Such features include young and highly luminous star clusters in the Galactic Center region, Arches cluster, Quintuplet cluster, and central cluster (e.g. Figer et al. 1999, Figer et al. 2002). Molecular clouds in the Galactic Center region are much denser, warmer, and more turbulent than disk clouds (e.g. Oka et al. 1998, Tsuboi, Handa, & Ukita 1999). In addition, the poloidal magnetic field of the Galactic center region is believed to be widely uniform and as strong as 1 mGauss (Yusef-Zadeh & Morris 1987a, Yusef-Zadeh & Morris 1987b). Such a strong magnetic field can inhibit star formation in the Galactic center region (e.g. Morris 1989, Stahler & Palla 2004). It is an open question what mechanism is responsible for the formation of such bright star clusters around the Galactic Center. On the other hand, objections have arisen to the idea of the presence of a strong and ubiquitous magnetic field in the region following recent low frequency radio observations (LaRosa et al. 2005).

The "50-km s$^{-1}$ molecular cloud" which is located only 3′ from Sagittarius (Sgr) A* is a most remarkable Galactic Center molecular cloud (see figure 3 in Tsuboi, Handa, & Ukita 1999), involving compact HII regions (Ekers et al. 1983, Goss et al. 1985). The cloud appears to be connected to another remarkable cloud, the 20 km s$^{-1}$ molecular cloud, by an extended molecular belt which stretches along the Galactic plane. On the other hand, the morphological relationship between the 50-km s$^{-1}$ molecular cloud and the Sgr A east shell, which is presumably a luminous and young SNR located in the Galactic Center region, suggests a physical interaction (e.g. Ho et al. 1985). The interaction of SNRs with the molecular clouds may play an important role in star formation in the Galactic Center region, just as in the Galactic disk region. Detailed observations of the dense molecular cloud of the Galactic Center region should provide unprecedented information about the mechanism of star formation in the Galactic Center region.

We have observed the detailed structure of the 50-km s$^{-1}$ molecular cloud in the CS $J = 1 - 0$ line using the Nobeyama Millimeter Array (NMA) of Nobeyama Radio Observatory$^1$. CS emission is expected to be almost free of the strong contamination near 0 km s$^{-1}$ from the foreground and background disk molecular clouds because it has a high critical density, $n(H_2) \simeq 10^4$ cm$^{-3}$. Only the NMA can make high resolution observations in the CS $J = 1 - 0$ line with a wide field of view.

Throughout this paper, we will adopt 8.5 kpc as the distance of the Galactic Center. At this distance, 1 pc corresponds to about 24′. And we use galactic coordinates. North in this paper means north in galactic coordinates. South, east, and west are also similar.

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$^1$ Nobeyama Radio Observatory is a branch of the National Astronomical Observatory, National Institutes of Natural Sciences, Japan
2. Observations and Data Analysis

The 50-km s\(^{-1}\) molecular cloud, which is centered at \(l = 359^\circ 58' 54.8''\), \(b = -0^\circ 4' 18.8''\), was observed with NMA in the CS \(J = 1 - 0\) line (48.990964GHz) in the winter of 1988. Five 10-m antenna elements of the NMA were available in this season. We obtained fifty baseline data. Total on-source integration time was about 20 hours. The FWHM (Full Width at Half Maximum) of the antenna elements is 156" at 49 GHz. Fig. 1 demonstrates the relative location of the outer boundary of the FWHM, the 50 km s\(^{-1}\) molecular cloud in CS \(J = 1 - 0\) line from the 45-m telescope (Tsuboi, Handa, & Ukita 1999), and the Sgr A east shell at 5 GHz (Yusef-Zadeh & Morris 1987a). This included the 50-km s\(^{-1}\) molecular cloud and the south-east edge of the Sgr A east shell. It was difficult to make a mapping of the field in the vicinity of a strong source such as the Sgr A west because the side lobes of a strong source in dirty maps induce residuals that overwhelm faint structures in clean maps. We chose the field center so that the Sgr A west was settled in the first null of the antenna primary response of the NMA. Thus the resultant maps were almost free of artifacts with Sgr A west.

The receivers of the NMA at 49 GHz were SIS mixer receivers. The system noise temperature, including atmospheric noise, was about 400 K during the observations. The back end was an FX-type digital correlator. The total velocity coverage and velocity resolution were 490 km s\(^{-1}\) and 0.48 km s\(^{-1}\), respectively. We used NRAO530 as the phase and gain calibration source, of which flux density during observations was assumed to be 7.0 Jy at 49 GHz. The absolute flux density scale was established using Uranus and Mars.

In order to make maps, we used a CLEAN method in the NRAO AIPS package. The size of the synthesized beam was 8.5" × 10" (\(\phi = 24^\circ\)) with a natural weighting, which corresponds to about 0.35 pc ×0.42 pc. Features with spatial extensions larger than 1' were resolved out. Therefore, the NMA is best used as a spatial filter to find compact components. Finally, a comparison of the C\(^{32}\)S \(J = 1 - 0\) and C\(^{34}\)S \(J = 1 - 0\) lines observed by the NRO 45-m telescope indicates that averaged optical depth of the C\(^{32}\)S \(J = 1 - 0\) line is about 3 in the central part of the 50-km s\(^{-1}\) molecular cloud (Tsuboi, Handa, & Ukita 1999). We keep in mind in the following analysis that the CS \(J = 1 - 0\) line is moderate optically thick.

3. Results

Fig. 2 shows the velocity channel map taken with the NMA of the CS \(J = 1 - 0\) emission toward the 50 km s\(^{-1}\) molecular cloud. The velocity width of each panel is 3.8 km s\(^{-1}\). The r.m.s. noise levels of the resultant maps are about 50 mJy beam\(^{-1}\) at the center of the panel. It should be noted here that all panels in this figure are corrected for the primary beam attenuation of the element antenna. The molecular cloud can be detected in panels with \(V_{\text{LSR}} = 10.6 - 83.2\) km s\(^{-1}\). The molecular cloud is resolved into many clumps and/or several filaments in the channel maps. The Sgr A east shell is located northwest of the cloud, but it is already faded
Fig. 1. Relative location among the FWHM of the 10-m antenna elements of NMA (thick circle), the 50 km s$^{-1}$ molecular cloud in CS $J = 1 - 0$ line with the 45-m telescope (contours; Tsuboi, Handa, & Ukita 1999), and the Sgr A east at 5 GHz (gray scale; Yusef-Zadeh & Morris 1987a). The FWHM of NMA is about 156" at 49 GHz. 

out at these frequencies. In the velocity range of $V_{\text{LSR}} = 10.6 - 52.7$ km s$^{-1}$, the molecular cloud is elongated mainly southwest to northeast. The clouds with more positive velocities have more complicated structure.

Fig. 3 shows a velocity-integrated map of the 50-km s$^{-1}$ molecular cloud. The integrated velocity range is $V_{\text{LSR}} = 9 - 74$ km s$^{-1}$, and covers almost all of the 50-km s$^{-1}$ molecular cloud. This figure is corrected for the primary beam attenuation of the element antenna. Although the molecular cloud in the lower-resolution map is smooth and has a triangular shape (also see figure 1), the higher-resolution map shows that the CS $J = 1 - 0$ intensity in the cloud is concentrated in three different spatial components, which will be discussed in later sections. The emission of CS $J = 1 - 0$ detected within the FWHM by the NMA is about 63% of that detected by the NRO 45-m telescope. The circle in the figure shows the outer boundary of the FWHM ($D = 156"$) of the NMA. However, in this observation, there is no significant increase in noise level and no strong contamination source up to within $D = 180"$. Fig. 4 is the position-velocity diagram along the line through these components (thick line in Fig.3). The 50 km s$^{-1}$
Fig. 2. Velocity channel maps of CS $J = 1 - 0$ emission with the NMA toward the 50-km s$^{-1}$ molecular cloud. The velocity width of each panel is 3.8 km s$^{-1}$. The numbers in the top left corners show the central LSR velocities of the each panel. The size of the synthesized beam is 8.5$''$ $\times$ 10$''$ ($\phi = 24^\circ$) and is shown in the bottom right corner. The lowest contour level and the contour interval are both 210 mJy beam$^{-1}$. The circle in the figure shows the outer boundary of the FWHM, $D = 156''$, of the 10-m antenna elements of the NMA. All panels in this figure are corrected for the primary beam attenuation of the element antenna.
Fig. 3. Velocity-integrated CS $J = 1 - 0$ map of the 50 km s$^{-1}$ molecular cloud. The integrated velocity range is $V_{\text{LSR}} = 9 - 74$ km s$^{-1}$. The size of the synthesized beam is $8.5'' \times 10'' (\phi = 24^\circ)$ and is shown in the bottom right corner. The circle shows the outer boundary of the FWHM, $D = 156''$, of the 10-m antenna elements of the NMA. This figure is corrected for the primary beam attenuation of the element antenna. The lowest contour level and the contour interval are both 82 mJy beam$^{-1}$, which correspond to $4 \sigma$ level at the center of the FWHM. The emission detected within the FWHM of the 10-m antenna elements of the NMA is about 63 % of that detected by the NRO 45-m telescope. An image of the Sgr A east at 5 GHz continuum map (red contours; Yusef-Zadeh & Morris 1987a) overlaid on the map. Open circles show the positions of OH masers (Sjouwerman & Pihlström 2008).
molecular cloud is seen as an inclined ridge in the diagram. The velocity width increases up to 60 km s\(^{-1}\) in these components. This velocity width is three times larger than those of other parts of the 50 km s\(^{-1}\) molecular cloud and 10 times wider than those expected from their sizes based on the size-velocity width relation for disk clouds. Fig. 3 also shows the relation between the 50-km s\(^{-1}\) molecular cloud and the Sgr A east shell. The red contours in the figure indicate the continuum emission at 5 GHz of the Sgr A east shell (Yusef-Zadeh & Morris 1987a).

A component is centered at an apparent contact point of the molecular cloud with the shell, \(l = -1.3', b = -3.5'\). This "northwest" component is elongated along the boundary of the Sgr A east shell. The component is also identified in the channel maps with \(V_{\text{LSR}} = 18.2 - 60.3\text{kms}^{-1}\) (see Fig. 2). The southwestern boundary apparently intrudes into the break of the Sgr A east shell, which is darker than other parts of the shell. The ragged outer limb appears to fit in the inner edge of the break of the shell. There would be a detailed morphological complementarity between the molecular cloud and the Sgr A east shell. The velocity width of the northwest is up to 50 km s\(^{-1}\). \(\text{H}_2\) emission has also been observed in the vicinity of the component (Yusef-Zadeh et al. 2001, Lee, S. et al. 2003). The morphology of this CS emission is dissimilar to that of the \(\text{NH}_3\) emission (see Fig.3 in Mcgary, Coil, & Ho 2001). The south extension standing out in the \(\text{NH}_3\) emission is relatively weak in CS emission. This corresponds to the OH SNR masers being distributed along the Sgr A east shell (see Fig.3 and fig.1 in Sjouwerman & Pihlström 2008). If the morphologies are caused only by snowplow effect of the Sgr A east shell, these morphologies should resemble each other. In addition, the interaction should have started up to a few 1000 years ago because the age of the Sgr A east shell is expected to be about 1500-10000 years from X-ray observations (e.g. Fryer et al. 2006, Koyama et al. 2007). Molecular gas even with a velocity of 100 km s\(^{-1}\) moves only 0.1 pc, or 2.4" in 1000 years. The time after the beginning of the interaction is too short to form the elongated appearance only by snowplow effect. The morphologies are probably caused by an increase in the fractional abundance of CS molecule with shock and/or a decrease in that of the \(\text{NH}_3\) molecule with photodissociation (Fuente et al. 1993).

The second component is centered at \(l = -1.0', b = -4.2'\). This "central" component is elongated from southwest to northeast, and not necessarily along the boundary of the Sgr A east shell. The component has velocity of \(V_{\text{LSR}} = 22.1 - 56.7\text{ km s}^{-1}\) (see Fig. 2). The velocity width is up to 40 km s\(^{-1}\) at the component although it is just outside of the Sgr A east shell. The northernmost of the compact HII regions is associated with this component apparently. The LSR velocity of the recombination line of these HII regions, \(V_{\text{LSR}} = 14 - 72\text{ km s}^{-1}\), corresponds approximately to that of the molecular cloud (Ekers et al. 1983, Goss et al. 1985). The line profile of the component has only a negative velocity wing. Although the sensitivity of NMA at the time may prevent us from detecting a positive velocity wing, any positive velocity wing is much weaker than the negative one. Collisionally-excited OH masers (1720 MHz) have been observed between the central and northwest components (Pihlström&
Fig. 4. Position-velocity diagram along the thick line in figure 3. The velocity widths at angular offsets of 0.7, 0, and −0.7 are three times wider than those of other parts of the Galactic Center molecular cloud (e.g. Oka et al. 1998, Tsuboi, Handa, & Ukita 1999).


The third component is located to the lower left of the "central" component. This "southeast" component has an LSR velocity of $V_{\text{LSR}} = 10.8 - 41.2$ km s$^{-1}$ (see Fig. 2). The elongation of the component is from south to north direction. The velocity width is up to 60 km s$^{-1}$ at the component although it is far from the Sgr A east shell. The large velocity width of the components without the interaction to the Sgr A east shell is discussed in the next section.

4. Discussion

4.1. An expanding molecular shell in the 50 km s$^{-1}$ molecular cloud

Fig. 5a shows a velocity-integrated map (contours and gray scale) of the 50 km s$^{-1}$ molecular cloud with velocity range of $V_{\text{LSR}} = 50 - 70$ km s$^{-1}$. There is a ring-like structure with $D = 100''$ at $l = -1^110'', b = -4^330''$ (also see panels with $V_{\text{LSR}} = 48.8 - 67.9$ km s$^{-1}$ in Fig. 2). Fig. 6 shows position-velocity diagram of CS $J = 1 - 0$ emission along galactic latitude at $l = -1'$. There is a ring-like feature centered at $b = -4^330''$ and $V_{\text{LSR}} = 35$ km s$^{-1}$. The galactic latitude
Fig. 5. a Velocity-integrated map (contours and gray scale) of the 50 km s$^{-1}$ molecular cloud. The velocity range is $V_{\text{LSR}} = 50 - 70$ km s$^{-1}$. There is a ring-like feature with a diameter of $D = 100''$ centered at $l = -1^\circ 30''$, $b = -4^\circ 10''$ (the circle with the dashed line). b An image at 94 GHz observed by NRO 45-m telescope (thick contour; Tsuboi et al. 1988, Tsuboi, Miyazaki, & Handa 2006) overlaid on an image at 5 GHz (thin contour; Yusef-Zadeh & Morris 1987a). c An image of 850 $\mu$m observed by JCMT 15-m telescope (contour; Pierce-Price et al. 2000) overlaid on an image at 8 $\mu$m observed by Spitzer (gray scale; Stolovy et al. 2006). d An image of 0.33 GHz observed by VLA (Pedlar et al. 1989).
Fig. 6. Position-velocity diagram of CS $J = 1 - 0$ emission along galactic latitude at $l = -1'$. There is a ring-like feature centered at $b = -4'10''$ and $V_{\text{LSR}} = 35 \text{ km s}^{-1}$ (the oval with the dashed line) with the galactic latitude width $\Delta b = 100''$ and the velocity width of $\Delta V_{\text{LSR}} = 55 \text{ km s}^{-1}$.

The ring-like feature in the position-velocity diagram indicates that the molecular shell has radial motion of $V_{\text{LSR}} = 28 \text{ km s}^{-1}$. Because it is not likely that such a well-shaped ring-like feature in the diagram has been produced by contraction of the shell, the motion is presumably expansion. Then a new expanding shell-like structure is found in the 50 km s$^{-1}$ molecular cloud as an interior cavity. The wide velocity dispersion of the "southeast" component (at angular offset = $-0'.7$ in Fig.4) is produced by the expanding molecular shell. The velocity dispersion of the "central" component may be also affected by the shell. In addition, the expanding shell-like structure may correspond to a circular decrement of $[\text{CII}]$ line in the 50 km s$^{-1}$ molecular cloud (see fig.2 in Poglitsch et al. 1991).

Fig.5b shows a 94-GHz continuum emission in the same region of Fig 5a with the NRO 45-m telescope (Tsuboi et al. 1988, Tsuboi, Miyazaki, & Handa 2006 ). This emission may be extended concentrically and concentrated at the center of the shell. This would involve the famous neighboring compact HII regions (Goss et al. 1985, also see Fig.5c). Morphological complementarity between the expanding molecular shell and the extended feature suggests that an interior cavity of the expanding molecular shell is filled up by it. The feature is also identified clearly at 43 GHz (e.g. Tsuboi, Miyazaki, & Handa 2006 ). But this is not clear below 5 GHz (Yusef-Zadeh & Morris 1987a). Moreover, the 0.33-GHz brightness is identified as a
shallow depression at the center of the 94-GHz continuum emission (see Fig.5d). The integrated intensities at 43 and 94 GHz are 8.5 and 5.0 Jy, respectively. Although these values involve contributions surrounding the Sgr A complex, for example 1 and 0.9 Jy from the compact HII regions, the spectrum of the extended continuum feature is fairly steep rather than flat. Then the extended feature may not trace the HII region. This is presumably an SNR. We should definitely answer the question of why the SNR is not clear below 5 GHz. The material surrounding the SNR is shocked and ionized at least partially because the kinetic energy per molecule estimated from the observed velocity width, $KE = 4 \times 10^{-18}$ J, is comparable to ionization energy of the Hydrogen molecule, $KE = 2 \times 10^{-18}$ J. The ionized sheath may hide the embedding SNR below 5 GHz. In addition, this feature cannot be identified as an independent source in X-ray because it is located in the X-ray emitting envelope surrounding the Sgr A complex (Baganoff et al. 2003).

Fig.5c shows the relation between the expanding molecular shell and the 850$\mu$m continuum emission with JCMT indicating distribution of hot dust (Pierce-Price et al. 2000) overlaid on an image at 8 $\mu$m observed by Spitzer (Gary scale; Stolovy et al. 2006). The distribution of hot dust presumably traces the east and north limbs of the shell and the feature associated with compact HII regions. On the other hand, the relation between the 850$\mu$m continuum and the "northwest" component elongated along the Sgr A east shell (also see Fig.3) is not clear. The 850$\mu$m continuum seems to trace the molecular gas traced by the NH$_3$ emission (Mcgary, Coil, & Ho 2001). The "northwest" component presumably does not contain as much dust as expected from the CS $J = 1 - 0$ emission. The interaction may emphasis the CS $J = 1 - 0$ line from the "northwest" component.

The kinetic energy of the expanding molecular shell is expected to be $7 \times 10^{49}$ erg, assuming that the diameter, the thickness, the expanding velocity, and the H$_2$ density are 4.2 pc, 0.3 pc, 28 kms$^{-1}$, and $1 \times 10^4$ cm$^{-3}$, respectively. The kinetic energy is as large as the energy of a single supernova. If the shell is expanding from the central point and the expanding velocity is constant, the age of the shell is estimated to be $7 \times 10^4$ years. If a supernova made the expanding molecular shell and the shell was expanding and decelerating, the age should be much less than $10^5$ years. The SNR hypothesis is a possible answer why the velocity width of the components not interacting with the Sgr A east shell is large. However, the energy emitted by an O5 star for $10^5$ years comes up to the kinetic energy. It cannot be ruled out with the energy balance that a few embedded O stars produced an HII region and drove the expansion of the molecular shell. In that case, we should answer the question why the HII region apparently, at least, has an observed steep spectrum.

4.2. Magnetic field in the 50 km s$^{-1}$ molecular cloud

Fig. 7 shows the comparison between CS emission with $V_{LSR} = 9 - 74$ km s$^{-1}$ in 50 km s$^{-1}$ molecular cloud and 350 $\mu$m polarization (H-vector) in the cloud observed by Novak et al.
Fig. 7. The magnetic field by 350 $\mu$m polarimetric observation (Novak et al. 2000) was overlaid on a velocity-integrated map of the 50 km s$^{-1}$ molecular cloud, which is the same as Fig. 3. Each bar indicates a sky position of polarization, which is parallel to the magnetic field. The magnetic field lines are predominantly along the axis of the elongated structures in the cloud. The magnetic field lines are well-ordered in the 50 km s$^{-1}$ cloud. The magnetic field lines are oriented along the elongations of the components in the cloud. The elongations are aligned along the south-southwest to north-northeast with about 30$^\circ$ deviation. The polarization is caused by dust alignment by the magnetic field in the cloud and shows the distribution. Although large-scale magnetic fields in the Galactic center region are poloidal (e.g. Tsuboi et al. 1986), recent sub-millimeter wide-area observation (Chuss et al. 2003) indicates the magnetic fields in the CMZ are oriented approximately parallel to the Galactic plane. Molecular clouds near the Galactic center would have suffered from tidal shear and deformed into a configuration stretching along an axis toward Sgr A. Then the magnetic field lines are apparently oriented along the axis because of being flux-frozen to the partially ionized molecular gas. However, the magnetic field lines in the 50 km s$^{-1}$ molecular cloud are beyond this tendency. The 50 km s$^{-1}$ molecular cloud is probably located in the halo of Sgr A, which will be mentioned in the next subsection. There are the ”protrusions” in the halo (Yusef-Zadeh & Morris 1987a, also see Fig. 1). They are filamentary nonthermal structures protruding from near Sgr A west predominantly along the south to north. The morphology should show that poloidal field is standing out in the halo, similar to the outer region. The dust polarization in Fig. 7 is oriented
approximately parallel to the poloidal field in the halo. The dust in the cloud would have been aligned by the existing magnetic field.

Another mechanism interpreting the polarization in the cloud may be compression with SNRs surrounding the cloud. If the cloud is elongated by the compression, the magnetic field lines should be predominantly along the elongation. Because at least the component at \( l = -1.3', b = -3.5' \) is located at the apparent contact point with the Sgr A east shell and the elongation is along the edge of the shell, this effect is partially consistent with the magnetic field in appearance. However, the other two components are displaced from the edge of the shell.

The strength of the magnetic field in the radio arc is estimated to be as strong as mGauss (Yusef-Zadeh & Morris 1987b, Tsuboi, Ukita, & Handa 1997). However, it is still an open question whether the strength of the magnetic field in the larger area of the Galactic center region is as strong as mGauss or not. If there is a strong poloidal magnetic field in this region similar to that in the radio arc, magnetic pressure around the expanding molecular shell is comparable to its ram pressure and it must be elongated along the magnetic field direction. However, the shell has a well-shaped circular appearance in Fig.5a. The aspect ratio of the structure is less than 1.1. This suggests that the strength of the magnetic field in this region is less than the ram pressure. From the aspect ratio of the molecular shell, the strength is expected to be smaller than 100 \( \mu \)Gauss (Cf. LaRosa et al. 2005). The poloidal magnetic field is not uniform and may be condensed in some parts of the Galactic center region. Because a strong magnetic field in the Galactic center region can inhibit star formation (Morris 1989), the weak magnetic field estimated around the 50-km s\(^{-1}\) molecular cloud is consistent with on-going active star formation in the molecular cloud. In addition, there is no sign associating the expanding molecular shell in the magnetic field lines shown in Fig.7, which will be discussed in the next subsection. This is caused by the quantity difference between dust in the shell and the cloud itself. The latter is probably over several 10 times larger than the former.

4.3. The line-of-sight location of the 50 km s\(^{-1}\) molecular cloud

The line-of-sight location among the Sgr A west, the Sgr A east, and the 50 km s\(^{-1}\) cloud has been discussed by several authors (Coil& Ho 2000, Sandqvist 1989, and Zylka, Mezger, & Wink 1990). The radio shadow or silhouette of the Sgr A west against the Sgr A east shell at low frequency indicates that the Sgr A west is located in front of the Sgr A east shell (Pedlar et al. 1989). In addition, the OH absorption feature for the Sgr A east shell is detected only for the negative velocity wing of the 50 km s\(^{-1}\) cloud (Pihlström& Sjouwerman 2006, Sjouwerman & Pihlström 2008). An absorption feature is made only by the foreground molecular cloud with respect to a continuum source. These suggest that the 50 km s\(^{-1}\) molecular cloud is located in front of the Sgr A east shell, so that the Sgr A east shell crashes into the far side of the molecular cloud and blocks or suppresses the growth of shocked gas with positive velocity.
However, the distance between Sgr A west and east is not determined from these observations.

Fig. 5b shows comparison between 94-GHz and 5-GHz continuum emissions of the Sgr A region. As mentioned previously, the 94-GHz emitting region may be an SNR embedded in the expanding molecular shell because it has steep spectrum in mm-wave. However, no counterpart at 5 GHz is seen in Fig.5b. There is presumably an ionized sheath between these so that the surrounding ionized sheath obscures the SNR at 5 GHz because the optical depth is in inverse proportion to the square of frequency. Fig. 5d shows comparison between the expanding molecular shell and 0.33 GHz continuum of the Sgr A region (Pedlar et al. 1989). The Sgr A halo should have a steep spectrum. The ionized sheath is probably optically thick at 0.33 GHz. If the 50 km s$^{-1}$ molecular cloud including the SNR with the ionized sheath is located in front of the halo, it should be seen as an absorption. The 0.33-GHz brightness is depressed certainly but shallowly at the center of the 94-GHz continuum emission as mentioned in the previous section. This depression feature is also identified in 0.61 GHz (Roy & Pramesh 2004) although it is fainter than that in 0.33 GHz. Then the 50 km s$^{-1}$ molecular cloud is located deep in the Sgr A halo so that the foreground emission in the halo compensates for the depression. These may provide information about the distance between the Sgr A west and east, which is difficult to determine from observations as mentioned previously. Then these suggest the face-on view of this region shown in Fig. 8. As is well known, the break of the Sgr A east shell is observed at 5 GHz toward the contact point between the 50 km s$^{-1}$ cloud and the
Sgr A east shell. However, no such clear break is seen in the 0.33-GHz continuum map (Pedlar et al. 1989). These are explained by the hypothesis that the Sgr A east shell crashed into the 50 km s$^{-1}$ molecular cloud along the direction fairly inclined to the line of sight, as shown in Fig.8, so that the break is concealed by the shell itself because it is somewhat optically thick at 0.33 GHz. Although CS $J = 1 – 0$ line in the cloud has moderate thickness (Tsuboi, Handa, & Ukita 1999), there is no absorption for the molecular cloud towards the compact H$^{\text{ii}}$ regions (see Fig.3). The compact H$^{\text{ii}}$ regions are located in front of 50 km s$^{-1}$ molecular cloud. This is consistent with the compact H$^{\text{ii}}$ regions seen clearly in 8 $\mu$m image of Fig.5c.

5. Conclusions

We have obtained 8.5" $\times$ 10" resolution maps, using NMA, in CS $J = 1 – 0$ line emission of the 50-km s$^{-1}$ molecular cloud being adjacent to the Sgr A east shell in the Galactic Center region. The molecular cloud is mainly concentrated in three different spatial components with large velocity widths of up to 60 km s$^{-1}$. The ”northwest” component is located at an apparent contact point with the Sgr A east shell and is elongated along the boundary of the shell. The interaction with the Sgr A east shell is responsible for large velocity width of the component. The ”central” and ”southwest” components are located in the vicinity of the Sgr A east shell but have no contact with it. We found a well-shaped circular molecular shell in the cloud. This molecular shell has expanding motion of 28 km s$^{-1}$. The expanding molecular shell should cause large velocity dispersion in the other two components. A steep spectrum source is detected in the central cavity of this molecular shell in the mm-wave continuum. This source is not identified in the previous 5-GHz map. This continuum source may be an SNR surrounded by an ionized sheath. The ionized sheath obscures the SNR at 5 GHz. From the aspect ratio of the expanding molecular shell of 1.1, the magnetic field is estimated to be smaller than 100$\mu$ Gauss in/around the cloud. The estimated weak magnetic field is consistent with on-going active star formation in the cloud. The comparison among CS line emission, low frequency continuum, and and millimeter continuum toward the 50-km s$^{-1}$ molecular cloud suggests that the molecular cloud is located in the Sgr A halo region.

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