

THE SPATIAL SCALE OF GLYCOLALDEHYDE IN THE GALACTIC CENTER

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ABSTRACT

We previously reported the spectral detection of the first interstellar sugar, which is known as glycolaldehyde (CH_2OHCHO), by observing six separate millimeter-wave rotational transitions with the NRAO 12 m telescope while pointed toward the Sagittarius B2 North hot core source known as the Large Molecule Heimat (LMH) source. In the present BIMA array work, we have spatially mapped Sgr B2 using the $8_{08-7_{17}}$ transition of glycolaldehyde at 82.4 GHz. We find that glycolaldehyde has a spatial scale of $\geq 60''$ unlike its isomers methyl formate and acetic acid, which are concentrated in the LMH source that has a spatial scale of $\leq 5''$. We estimate that the relative abundance ratios of (acetic acid) : (glycolaldehyde) : (methyl formate) are $\sim 1 : 0.5 : 26$ within the LMH source. It is likely that the conditions of the LMH source favor the chemically reactive nature of glycolaldehyde over its isomers and other large molecules such as dimethyl ether. The ensuing chemistry leads to glycolaldehyde destruction in the LMH source and glycolaldehyde survival outside of the LMH source in extended cloud extremities. This scenario is supported by comparison of line widths, which shows that glycolaldehyde possesses a factor of 2–3 greater line width than those of other complex molecules that are confined largely to the LMH source.

Subject headings: ISM: abundances — ISM: clouds — ISM: individual (Sagittarius B2) — ISM: molecules — radio lines: ISM

1. INTRODUCTION

The recent identification of interstellar glycolaldehyde, the simplest possible aldehyde sugar, was accomplished by observing six spectral transitions toward Sagittarius B2(N-LMH) with the NRAO 12 m telescope (Hollis, Lovas, & Jewell 2000). The telescope half-power beamwidths employed were $\sim 87''$, $\sim 84''$, $\sim 77''$, $\sim 68''$, and $\sim 61''$ at the 71, 75, 82, 93, and 103 GHz observing frequencies, respectively. Since the detection of interstellar glycolaldehyde was a classic spectral identification with a single antenna of considerable beamwidth, no detailed spatial information was obtained. Hence, we subsequently proposed to determine the spatial extent of the $8_{08-7_{17}}$ transition of glycolaldehyde at 82.4 GHz with the Berkeley-Illinois-Maryland Association (BIMA) array because this particular transition is, at present, the strongest glycolaldehyde emission line detected and apparently free of contamination from other molecular species, and this transition can easily be compared to a strong blend of ethyl cyanide and three dimethyl ether lines that are in spectral proximity. We expected the glycolaldehyde transition to spatially map like other large interstellar molecules found in the Large Molecule Heimat (LMH) source, and, in particular, like the very abundant and ubiquitous interstellar molecule methyl formate, which is an isomer of glycolaldehyde and acetic acid. Hence, we proposed to simultaneously observe both the $8_{08-7_{17}}$ transition of glycolaldehyde and the ethyl cyanide-dimethyl ether complex in one BIMA array correlator bandpass and a number of a-type and b-type methyl formate transitions in the other three bandpasses (see Table 1).

2. OBSERVATIONS AND RESULTS

Observations of glycolaldehyde were conducted with the BIMA array in the C (2000 July 11, 20, 22 and October 29, 31), D (2000 October 21), and B (2001 January 19, 21) configurations with baselines ranging between 7 and 240 m, which correspond to $\sim \lambda 1900$ and $\sim \lambda 66000$, respectively. The J2000 phase center positions used were the nominal position of Sgr B2(N-LMH) at $\alpha = 17^{\text{h}}47^{\text{m}}19^{\text{s}}.8$ and $\delta = -28^{\circ}22'17''$ during the summer of 2000 and a position located between the north and main continuum positions at $\alpha = 17^{\text{h}}47^{\text{m}}19^{\text{s}}.8$ and $\delta = -28^{\circ}22'39''$ for the remaining dates. The primary beam size was $2.2'$ at the 82.4 GHz observing frequency, and system temperatures near source transit ranged from ~ 270 to ~ 900 K. Data were calibrated, mapped, CLEANed, and self-calibrated using the MIRIAD package. The correlator was divided into four frequency windows, each with a bandwidth of 50 MHz and 128 channels, resulting in a spectral resolution of 0.39 MHz ($\sim 1.42 \text{ km s}^{-1}$) per channel. Spectra at the Sgr B2(N-LMH) and Sgr B2(M) positions for the four correlator windows shown in Figure 1 were extracted from the resulting CLEAN images assuming an LSR source velocity of 64 km s^{-1} (see Mehringer et al. 1997). Spatial images of the Figure 1 spectral features (i.e., blend of ethyl cyanide–dimethyl ether, glycolaldehyde, and methyl formate) and underlying continuum emission are shown in Figure 2 for a uniformly weighted synthesized beam ($6''.16 \times 1''.61$, P.A. = 0°) and a naturally weighted synthesized beam ($12''.3 \times 5''.9$, P.A. = 4°).

We expected that the BIMA array would produce an easy detection of the $8_{08-7_{17}}$ transition of glycolaldehyde since the NRAO 12 m telescope yields a flux of $1.5 \pm 0.2 \text{ Jy}$ for this transition (Hollis et al. 2000). However, as Figures 1 and 2 show, the flux recorded for glycolaldehyde by the BIMA array falls far short of those expectations. Figure 3 is a comparison of glycolaldehyde spectra taken with the NRAO 12 m (FWHM beam of $\sim 77''$) and the BIMA array (synthesized beam $\sim 12'' \times 6''$), suggesting that most of the flux for a blend of ethyl cyanide and dimethyl ether lines nearby is recovered but

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TABLE 1
PARAMETERS^a OF MOLECULAR LINES OBSERVED TOWARD SGR B2(N-LMH)

Molecule (1)	Transition (2)	Symmetry State (3)	Frequency ^b (MHz) (4)	E_u (cm ⁻¹) (5)	$S\mu^2$ (D ²) (6)	Figure 1 Flag (7)
(CH ₃) ₂ O	11 _{1,10} -11 _{0,11}	AE + EA	82456.986(3)	43.7	9.6	A
	11 _{1,10} -11 _{0,11}	EE	82458.660(3)	B
	11 _{1,10} -11 _{0,11}	AA	82460.334(4)	C
CH ₃ CH ₂ CN	9 ₁₈ -8 ₁₇		82458.62(01)	14.5	131.7	D
CH ₂ OHCHO	8 ₀₈ -7 ₁₇		82470.670(4)	13.1	34.2	E
HCOOCH ₃	7 ₁₇ -6 ₀₆	E	82242.942(12)	11.0	2.4	F
	7 ₁₇ -6 ₀₆	A	82244.488(14)	11.0	2.4	G
	7 ₅₂ -6 ₅₁	E	86021.008(12)	23.0	9.2	H
	7 ₅₃ -6 ₅₂	E	86027.674(10)	23.0	9.2	I
	7 ₅₃ -6 ₅₂	A	86029.445(12)	23.0	9.2	J
	7 ₅₂ -6 ₅₁	A	86030.212(12)	23.0	9.2	K
	7 ₄₃ -6 ₄₂	A	86250.576(12)	18.9	12.7	L
	7 ₃₅ -6 ₃₄	A	86265.826(12)	15.6	15.4	M
	7 ₃₅ -6 ₃₄	E	86268.659(10)	15.7	15.7	N
			U86247.6(4)			
U-Lines			U86254.8(4)			

^a Parameter references: dimethyl ether (Gröner et al. 1998); ethyl cyanide (Lavas 1982); glycolaldehyde (Butler et al. 2001); methyl formate (Oesterling 1999).

^b Values in parentheses are the statistical uncertainties quoted in the references in footnote a; U-line uncertainties are estimated equivalent to the spectral resolution (see § 2).

that glycolaldehyde, which must be spatially extended with respect to the ethyl cyanide–dimethyl ether blend, is being resolved out by the higher resolution BIMA array.

Previously, Hollis et al. (2000) obtained Sgr B2(N-LMH) relative abundances of (acetic acid) : (glycolaldehyde) : (methyl formate) $\sim 1 : 4 : 26$ under the assumption that all were largely confined to the same small LMH source. However, as Figure 3 shows, the weak spectral feature at the glycolaldehyde frequency in the BIMA array data has a flux of ~ 0.2 Jy (scaled) or, equivalently, ~ 0.15 Jy (unscaled). Using the unscaled flux, we estimate that (acetic acid) : (glycolaldehyde) : (methyl formate) $\sim 1 : 0.5 : 26$ within the LMH source, a result that is

consistent with the observed preference for C–O–C backbone structures in other hot core studies (e.g., Millar et al. 1988; Mehringer et al. 1997). Note, however, that our BIMA array data are not sensitive enough in spatial scale to explicitly determine the abundance ratio of methyl formate to glycolaldehyde outside of the LMH source.

In order to estimate the spatial scale of glycolaldehyde emission, a Gaussian source of FWHM $1''$ was artificially located at the position of the LMH and was assumed to have the total flux and Gaussian line width of glycolaldehyde given by the NRAO 12 m observations. The interferometric visibilities for the actual BIMA array u - v tracks corresponding to such a model

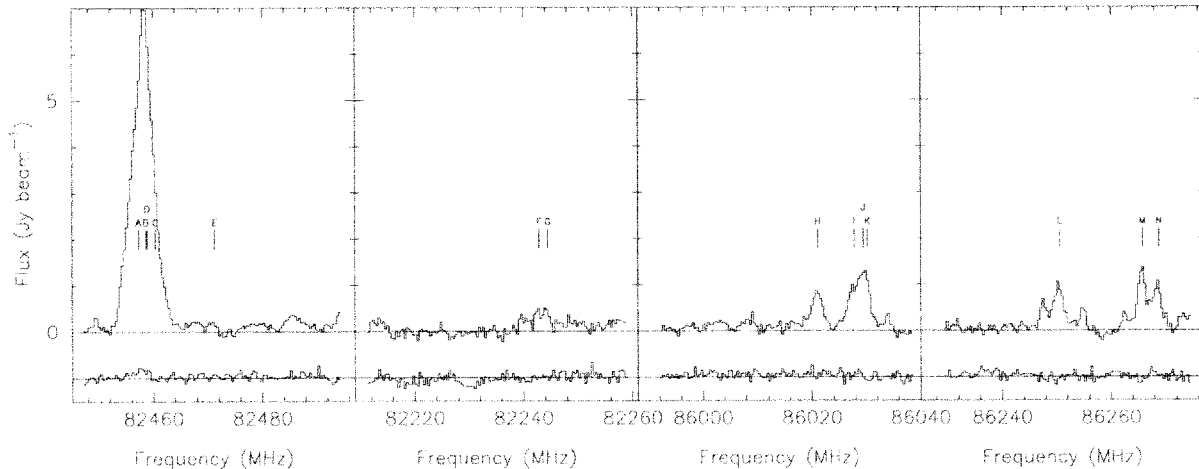


FIG. 1.—Spectra (top) of dimethyl ether, ethyl cyanide, glycolaldehyde, and methyl formate lines detected in Sgr B2(N-LMH) and line-free Sgr B2(M) comparison spectra (bottom) for all four correlator windows. All spectra were extracted from naturally weighted data cubes. In the presence of strong continuum, it is usually best to subtract the continuum in the u - v domain to produce a final spectrum, and this was done for Sgr B2(M). However, in Sgr B2(N-LMH) there is a forest of lines creating a pseudocontinuum. Thus, for each LMH correlator window, we selected frequency ranges that were relatively line-free as a better estimate of continuum. From an average of these frequency ranges, we constructed an LMH continuum image, which was then subtracted from all spectral channels in that correlator window. Parameters of molecular lines detected are shown in Table 1, with col. (7) giving the identification of fiducial flags. Not marked in the rightmost panel are two unidentified lines, U86247.6 and U86254.8, that flank the methyl formate L fiducial. The three rightmost correlator panels are somewhat noisier because these frequencies were not observed during the summer observations. Note that the spectra toward Sgr B2(M) are flatter, even though larger systematic errors would be expected in this direction because the continuum is twice as large; this effect is due to gain errors (i.e., errors in the amplitude or phase calibration, including the bandpass calibration) which are multiplicative and are therefore proportional to the signal strength. Therefore, spectra toward LMH show more structure due to the large number of lines.

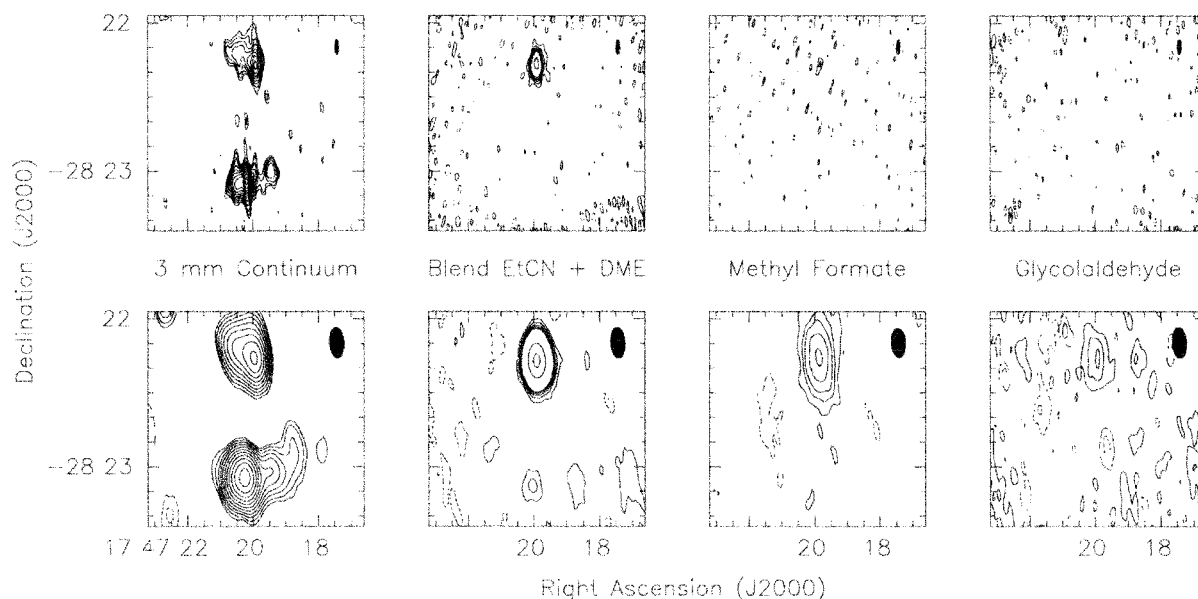


FIG. 2.—Sgr B2 contour images of 82 GHz continuum emission, the blend of ethyl cyanide–dimethyl ether emission shown in Fig. 1, the blend of $7_{53-6_{52}} E$ and A and $7_{52-6_{51}} A$ transitions of methyl formate shown in Fig. 1, and the $8_{08-7_{17}}$ transition of glycolaldehyde shown in Fig. 1. The top and bottom panels show images made with uniform and natural weighting, respectively, and all images have been corrected for primary beam attenuation. The beam size (see § 2) is shown in the upper right of each panel. The continuum images show Sgr B2(M) $\sim 40''$ south of Sgr B2(N), which contains the LMH position; the images are contoured in factor of $\sqrt{2}$ intervals, beginning at 0.2 and 0.1 Jy beam $^{-1}$ for the naturally and uniformly weighted images, respectively. The naturally weighted image has a peak of 7.8 Jy beam $^{-1}$, and the uniformly weighted image has a peak of 3.6 Jy beam $^{-1}$. The images labeled “Blend EtCN + DME” are integrated over the frequency range 82453.9–82463.2 MHz. The ethyl cyanide–dimethyl ether naturally weighted image is contoured at intervals of $\pm 2\%$, 4%, 6%, 8%, 10%, 50%, and 90% of the peak of 29.5 Jy MHz beam $^{-1}$. The ethyl cyanide–dimethyl ether uniformly weighted image is contoured at intervals of $\pm 10\%$, $\pm 20\%$, 30%, 40%, 50%, and 90% of the peak of 10.4 Jy MHz beam $^{-1}$. The images labeled “Methyl Formate” are integrated over the frequency range 86025.9–86031 MHz. The methyl formate naturally weighted image is contoured at intervals of $\pm 10\%$, $\pm 20\%$, 30%, 50%, and 90% of the peak of 5.15 Jy MHz beam $^{-1}$. The methyl formate uniformly weighted image is contoured at intervals of $\pm 50\%$ and 90% of the peak of 3.26 Jy MHz beam $^{-1}$. The images labeled “Glycolaldehyde” are integrated over the frequency range 82466.3–82474.1 MHz. The glycolaldehyde naturally weighted image is contoured at intervals of $\pm 25\%$, $\pm 50\%$, and 90% of the peak of 0.94 Jy MHz beam $^{-1}$ and shows evidence of weak emission. The glycolaldehyde uniformly weighted image is contoured at ± 0.78 , ± 1.17 , and 2.3 Jy MHz beam $^{-1}$ and shows that the weak emission is resolved out with such a narrow beam.

were added to the actual BIMA array visibility data, and a naturally weighted image was made. The model spectrum extracted from this image in Figure 4 (*top panel*) shows what would be observed by the BIMA array. For this $1''$ source size, the BIMA array should observe emission similar to that observed by the NRAO 12 m telescope (i.e., see Fig. 3). Figure 4 (*middle panel*) shows what the BIMA array would observe for a $30''$ FWHM source size. Both the BIMA array data and model + BIMA array data were tapered to produce a beam size matching the assumed source size. The spectra become noisier, but the BIMA array still recovers most of the emission. Figure 4 (*bottom panel*) shows the results for a $60''$ source size. At this scale size, the BIMA array resolves out about half the model flux. The recovered flux would drop rapidly for sizes larger than $60''$, suggesting that glycolaldehyde is greatly extended in comparison to the ethyl cyanide–dimethyl ether blend and methyl formate, which are largely confined to the compact LMH source as shown in Figure 2 images. It is well known that interferometers have difficulty mapping structures larger than $\theta \sim \lambda/D$, where D is the minimum baseline. For these observations, $D = 7$ m, implying $\theta = 105''$. However, the simulations show that the sensitivity is reduced even for structures somewhat smaller than $105''$.

3. DISCUSSION

A complete model of interstellar chemistry must account for the high degree of isomerism seen in interstellar clouds. For example, at present there are approximately 92 polyatomic mol-

ecules detected in interstellar clouds (Lovas & Snyder 2001), and 22 of these species are associated with eight isomeric pairs (e.g., dimethyl ether and ethanol) or two isomeric triplets (e.g., acetic acid, methyl formate, and glycolaldehyde). Clearly, one important characteristic of the interstellar molecule formation process must favor isomerism. If isomers are formed in a process containing common precursors like formaldehyde molecular building blocks (e.g., the formose reaction as per Larralde, Robertson, & Miller 1995) or functional molecular group building blocks self-assembling on grains and subsequently being released in to the gas phase (Hollis & Churchwell 2001), then it is reasonable to expect that such isomers would have similar spatial distributions.

We now consider the spatial distributions of methyl formate and glycolaldehyde toward Sgr B2(N-LMH) in this and previous work. Figure 2 shows that both methyl formate and glycolaldehyde have concentrations toward the LMH source, and Mehringer et al. (1997) have shown that methyl formate is confined largely to the LMH source. From NRAO 12 m data (Hollis et al. 2000), we find that the abundance ratio of methyl formate to glycolaldehyde is ~ 4.5 , which is a good measurement of the average line-of-sight abundance ratio, assuming that the sources of emission for these two molecules are smaller than the telescope beam. We should expect a similar ratio for BIMA array determined abundances if both molecules are largely concentrated in the LMH source. However, in the present BIMA array work we find that the abundance ratio of methyl formate to glycolaldehyde is ~ 50 for the LMH source

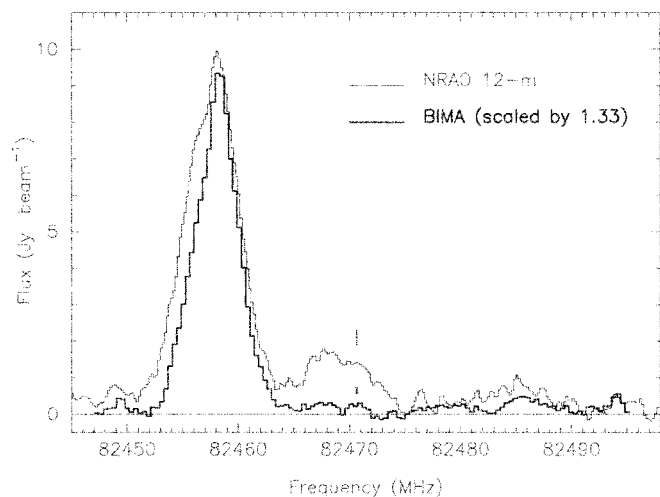


FIG. 3.—Spectral comparison of the $8_{08}-7_{17}$ transition of glycolaldehyde and the blend of ethyl cyanide–dimethyl ether emission toward Sgr B2(N-LMH) observed with the $77''$ beam of the NRAO 12 m telescope compared with that observed with the $12'' \times 6''$ naturally weighted BIMA Array beam. The $\pm 1\sigma$ error estimates are displayed at the glycolaldehyde rest frequency, showing ± 200 mJy for the NRAO 12 m data and ± 70 mJy for the BIMA array data. See Table 1 for rest frequencies and transitions pertaining to the emission features. The BIMA array spectrum is scaled up by a factor of 1.33 to approximately match the NRAO 12 m scale. This scaling is done to correct for possible flux calibration errors and emission extended over a region larger than the BIMA array beam. The glycolaldehyde emission is being resolved out by the BIMA array.

emission; such a large abundance ratio indicates that glycolaldehyde is deficient relative to methyl formate in the LMH source.

Considering the highly reactive nature of sugars in general, the deficiency of glycolaldehyde toward the LMH and the concentration of methyl formate toward the LMH source is consistent with enhanced gas-phase chemistry modifications in a hot molecular core. Indirect support for this spatial distribution scenario comes from the study of meteorites, which are undoubtedly formed in a process much hotter in comparison to temperatures realized in an interstellar molecular cloud core. Many biologically important compounds found in interstellar cloud hot cores are also found in meteorites (e.g., carboxylic acids, amides, etc.), but sugars are conspicuously absent in meteorite samples (e.g., Cooper 1998). Hence, the bulk of glycolaldehyde detected must be coming from the less dense cloud extremities in the vicinity of the LMH where fewer collisions translate to little or no gas-phase chemistry modifications.

Mehringer et al. (1997) mapped the isomers acetic acid and methyl formate in the Sgr B2(N-LMH) and found that both molecules were largely confined to a $\sim 5''$ diameter LMH source but their spatial distribution peaks were separated by as much as $\sim 3''$. These authors interpreted such a spatial separation between acetic acid and methyl formate as suggesting that significant differences in chemical processes were occurring in this hot core source. If that is the case, then the spatial distribution of either acetic acid or methyl formate as compared to the remaining interstellar isomer glycolaldehyde suggests an even more drastic chemistry process at work, which leaves acetic acid and methyl formate concentrated in the LMH source and glycolaldehyde primarily in less dense cloud extremities. This scenario is supported by a comparison of line widths, which show that glycolaldehyde possesses a factor of 2–3 greater line width than those of other complex molecules that

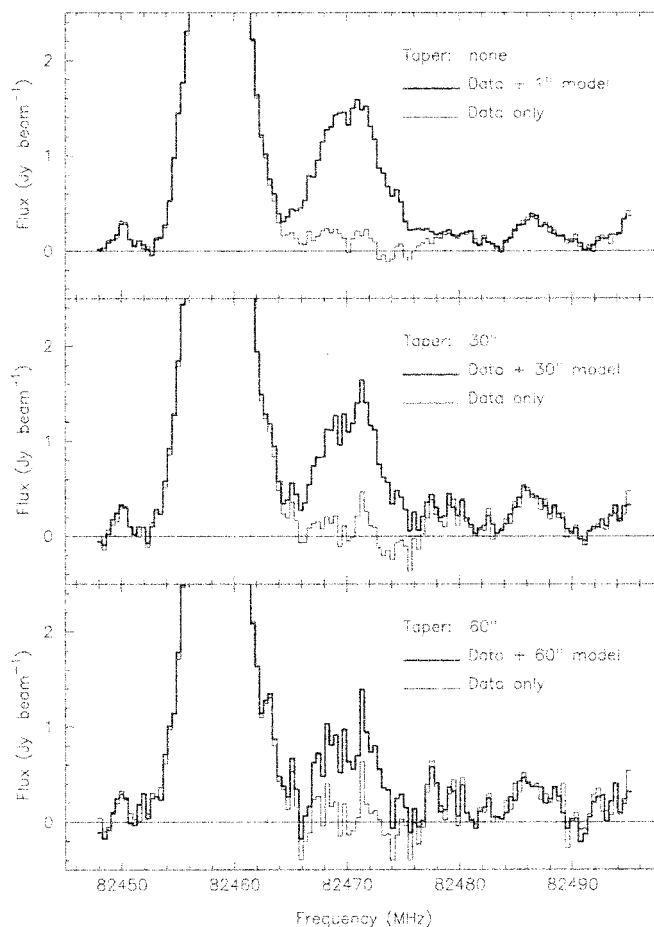


FIG. 4.—Comparison of observed Sgr B2(N-LMH) BIMA array spectra (*thin lines*) with spectra for model sources (*thick lines*) of various sizes that would be filtered by the BIMA array. See text for modeling details.

are confined largely to the LMH source. For example, in this work, an uncontaminated transition of methyl formate confined to the LMH source (designated H in Fig. 1) has a line width of $\sim 8.2 \pm 1.4$ km s $^{-1}$, while the $8_{08}-7_{17}$ transition of glycolaldehyde, which we have shown is not confined to the LMH source, has a line width of 24.3 ± 2.8 km s $^{-1}$ (Hollis et al. 2000).

In summary, we have determined that the spatial scale of glycolaldehyde must be $\geq 60''$ toward Sgr B2(N-LMH), while its isomers acetic acid and methyl formate are concentrated toward the LMH source that has a spatial scale of $\leq 5''$ (see Fig. 2 of Liu & Snyder 1999). We estimate that the relative abundance ratios of (acetic acid) : (glycolaldehyde) : (methyl formate) are $\sim 1 : 0.5 : 26$ within the LMH source. We suggest that enhanced gas-phase chemistry modifications may account for the differences in spatial scale among the three isomers. For example, it is likely that the conditions of the LMH favor the chemically reactive nature of glycolaldehyde over its isomers and other large molecules such as dimethyl ether. The ensuing chemistry leads to glycolaldehyde destruction in the LMH source and glycolaldehyde survival outside of the LMH in extended cloud extremities. This work demonstrates the virtue of a multi-instrument approach and the complementarity of single-antenna and interferometric observations for comparing the spatial distributions of complex molecules in order to provide clues regarding potential interstellar chemistries occurring in a given source.

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