The Forest From the Trees:

A 3-D View of the Inner 10 pc of the Galaxy from High-Resolution Spectral Line Images

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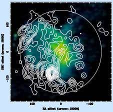
$NH_3(1,1)$



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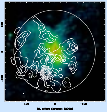
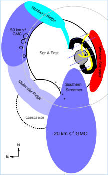
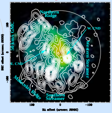
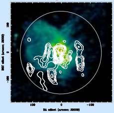




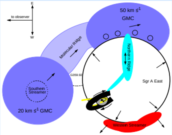
$NH_3(3,3)$



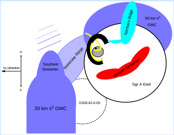
$NH_3(6,6)$



View from "Above"



View from the "Side"



Introduction

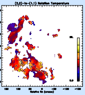
In this poster, we present the latest results from our project to study the molecular environment at the Galactic Center (GC) through VLA observations of NH_3 emission at 23 GHz (see MCH01 for details). These transitions are ideal for studying the GC because they trace warm, dense (10^5 cm^{-3}) gas. In addition, the hyperfine structure of the NH_3 lines allows for a direct calculation of opacity, and observations of multiple lines can be used to calculate the temperature, column density, and masses of clouds.

Above, we show velocity integrated maps of four transitions (with contour levels of 4σ) overlaid on a 6 cm continuum image (YM87) showing Sgr A East, Sgr A West, and Sgr A*. The circle marks the approximate extent of our VLA mosaic. We also show a schematic drawing of the face-on view of the same region. The southern streamer, western streamer, northern ridge, and CND, as well as the edges of the 50 km/s GMC and the molecular ridge are all detected in NH_3 and are labeled in the (3,3) map.

I. Derived Parameters

Using our VLA data, we have derived the following parameters for the molecular gas (HH04):

- intrinsic line width
- (1,1) and (2,2) opacity
- (2,2)-to-(1,1) rotation temperature
- column density
- excitation temperature
- cloud masses



Uncertainties in these parameters are calculated through Monte-Carlo simulations performed at each pixel.

Here, we show the derived rotation temperature for gas in the central 10 pc. Typical uncertainties in the rotation temperature are ~10%, with the largest uncertainties at cloud edges where there is low S/N.

II. The Impact (& Energy) of Sgr A East

Mezger et al. (1989) estimated a shell energy for Sgr A East of $\geq 2 \times 10^{51}$ ergs from ionized emission surrounding the shell. Based partially on the apparent concave morphology of the 50 km/s GMC, they assumed that Sgr A East had expanded into a medium with a mean density of 10^4 cm^{-3}. This implied a total energy of $\geq 4 \times 10^{52}$ ergs, more than a factor of 10 greater than a typical supernova.

Both the western streamer and 50 km/s GMC lie along the edge of Sgr A East. By comparing the physical properties of these clouds, we can directly measure the impact of Sgr A East on the molecular gas in the region.

Table 1: Comparison of 50 km/s GMC and Western Streamer

	50 km/s GMC	Western Streamer
Morphological Evidence?	NO*	YES
Median Line Width [km/s]	14+/-2	21+/-4
Velocity Gradient?	NO	YES: 25 km/s/pc
Average Rotation Temperature [K]	22+/-1	32+/-4
Implied Kinetic Temperature [K]	~25	~50
(6,6) emission detected?	NO	YES
Mass [solar masses]	~5x10^4	~1x10^3

*The apparent concave shape of the 50 km/s GMC was the result of the projection of the northern ridge along the LOS. This cloud has a velocity of -10 km/s and is NOT associated with the GMC (MCH01).

The western streamer shows many indications of a strong interaction with Sgr A East (see Table 1). However, the 50 km/s GMC is relatively unaffected by the impact of Sgr A East, and it is unlikely that the expanding shell has moved this material from the central parsecs.

If we assume that only the northern ridge and western streamer were swept up by the expansion of Sgr A East, then (based on Shull 1980) we calculate a mean initial density of 150 cm^{-3}, a total energy of $\geq 3 \times 10^{51}$ ergs, and a age of roughly 10^4 years. This result is consistent with other recent results that imply Sgr A East is the result of a single supernova event (see e.g. Maeda et al., 2002).

Schematic 3-D Model of the Central ~10 pc

The detailed physical parameters derived for these molecular clouds (see I) enable us to propose an updated picture of the central parsecs of the Galaxy. Schematic drawings of the LOS distribution of features are shown above. The locations of features are based on our molecular results as well as the results of many others. They are not intended to be to scale nor include every feature, but they are designed to give the "big picture" of the layout of the central parsecs.

Details of the Model:

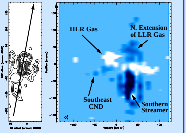
- Crosses mark 1720 OH masers (Yusef-Zadeh et al., 1999) and circles in the 50 km/s GMC denote HII regions. Dotted lines denote SNR G359.92-0.09 (Coil & Ho 2000).
- Sgr A West (yellow, (Roberts & Goss, 1993)) and the Circumnuclear Disk (CND) (backwards "C", (Gusten et al., 1987; Wright et al., 2001)) surround Sgr A* (central black dot). The exact location of these features relative to the front of Sgr A East is still debated, and I place them just at or slightly inside the shell based on Maeda et al. (2002).
- The 50 km/s GMC lies along the eastern edge of Sgr A East, where the impact has triggered star formation (see e.g. Pedlar et al. 1989). However, this GMC is NOT being significantly affected by the SNR (see II).
- The northern ridge has a constant velocity of -10 km/s and is physically distinct from the 50 km/s GMC. It shows kinematic evidence for being connected to the CND (see MCH01)
- The western streamer lies along the edge of Sgr A East, highly inclined to the line of sight. It is expanding outwards with the shell, resulting in a large velocity gradient and elevated temperatures (see II, MCH01).
- Based on absorption at 90 cm, the 20 km/s GMC must reside predominately in front of Sgr A West (see e.g. Pedlar et al., 1989). It is connected to the 50 km/s GMC along the molecular ridge (Coil & Ho 2000). The southern streamer does not show significant evidence for a connection to the CND and may simply be a projected cloud (see III). The faint extension of this feature to the north of the nucleus is shown as hatched lines.
- The high line ratio cloud seen only in (6,6) is likely confined within 1-2 pc of Sgr A*, but the exact morphology has not been determined (see III). It is therefore shown as a grey circle surrounding Sgr A*. Its origin is unknown, but it does not appear to come from the southern streamer.

Comments? Missing your favorite feature? Please find me and let me know!

III. The Central 2 pc & the Southern Streamer

In our (6,6) data, we detect a cloud of hot molecular gas <2 pc from Sgr A*. The line ratios and velocity gradients of this gas strongly indicate that is physically close to Sgr A* (HH02). But how is this cloud associated with other features in the region, and could it have originated in the southern streamer?

The figure below shows the location of a position-velocity cut overlaid on velocity integrated (6,6) emission. The cut begins in the south, and passes northwards through the southern streamer and the hot gas cloud near Sgr A*. The blue-scale image to the far right plots the DIFFERENCE between (6,6) and (3,3) at every position (and velocity) along this cut. Low Line Ratio (LLR) gas in which (6,6)-(3,3)<0 appears as dark blue to black, while white traces regions of high line ratio (HLR) gas where (6,6)-(3,3)>0. Sgr A* is at a position of 0".



The HLR gas has a very large velocity gradient from +100 km/s at -20" to -30 km/s at +30". (This gradient is in the opposite sense of gas in the CND.) While this cloud is very bright in (6,6), almost no (3,3) emission is seen from this feature and absorption effects must play a role within this cloud (HH04).

The LLR gas at 30 km/s comes from the southern streamer (note the satellite hyperfine lines). It shows no evidence for a velocity gradient in this region. There is also no obvious kinematic connection between the constant-velocity LLR gas and the HLR gas. In addition, we find a continuation of the LLR gas at 30 km/s to the NORTH of Sgr A* (positions 0"-60").

These results indicate that the southern streamer may be a projected extension of the 20 km/s GMC not directly associated with the CND or the HLR cloud. The projection of the southern streamer and the HLR gas cloud along the LOS could have resulted in the apparent increase in line width near Sgr A* observed in (1,1) and (2,2) by Coil & Ho (1999). The origin of the HLR cloud remains unclear.

References

Coil, A.L. & Ho, P.T.P. 1999, ApJ, 513, 752
Coil, A.L. & Ho, P.T.P. 2000, ApJ, 533, 245
Gusten, R. et al. 1987, ApJ, 318, 124
Herrnstein, R.M. & Ho, P.T.P. 2002, ApJ, 579, L83 (HH02)
Herrnstein, R.M. & Ho, P.T.P. 2004, in preparation (HH04)
Maeda, Y. et al. 2002, ApJ, 570, 671
McGary, R.S., Coil, A.L., & Ho, P.T.P. 2001, ApJ, 559, 326 (MCH01)
Mezger, P.G., et al. 1989, A&A, 209, 337
Pedlar, A. et al. 1989, ApJ, 342, 769
Roberts, D.A. & Goss, W.M. 1993, ApJS, 86, 133
Shull, J.M. 1980, ApJ, 237, 769
Wright, M.C.H. et al. 2001, ApJ, 551, 254
Yusef-Zadeh, F. & Morris, M. 1987, ApJ, 320, 545 (YM87)
Yusef-Zadeh, F. et al. 1999, ApJ, 512, 230

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