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Molecular Column Densities Near the Center of the Milky Way

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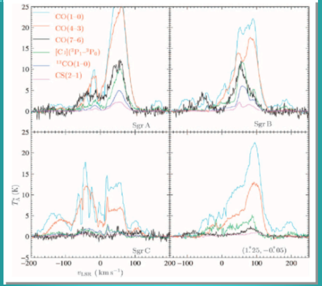
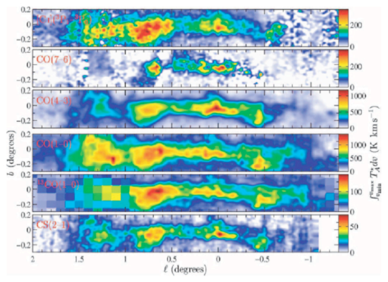
DATA PRESENTATION

Spectra toward the respective positions of peak CO J = 7→6 emission in the Sgr A (ℓ=0. 00°, b =−0. 07°), Sgr B (ℓ=0. 66°, b =−0. 05°), Sgr C (ℓ=−0. 45°, b =−0. 20°),(CO J =4→3 emission peak), and ℓz 1.3° (ℓ =1. 25°, b =−0. 05°) clouds (as indicated at lower right in each frame) in six different transitions, as indicated by the color identifications at upper left. The 461 GHz CO J =4→3, 807 GHz CO J =7→6, and 492 GHz [CI] $^3P_1 \rightarrow {}^3P_0$ data are from the AST/RO survey, and the 115 GHz CO J =1→0, 110 GHz ^{13}CO J =1→0, and 98 GHz CS J =1→0 data are from the Bell Laboratories 7 m telescope (Stark et al. 1988; Bally et al. 1987, 1988)



Spatial–spatial (ℓ,b) integrated intensity maps for the three transitions observed with AST/RO (top three panels) and, for comparison, the three transitions observed at the Bell Lab 7 m (Stark et al. 1988; Bally et al. 1987, 1988) (bottom three panels). Transitions are identified at left on each panel. The emission is integrated over all velocities where data are available. These values of (v_{min}, v_{max}) are [C I], (-90, 150); CO(7–6), (-30, 120); CO(4–3), (-150, 150); CO(1–0), (-150, 150); 13CO(1–0), (-150, 150); CS(2–1), (-150, 150). All six maps have been smoothed to the same 2' resolution.



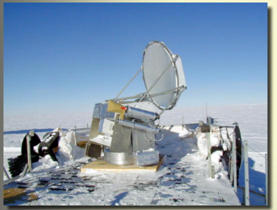
INTRODUCTION

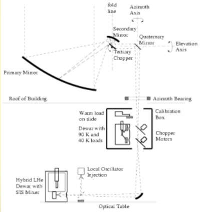
Much has been learned about dense gas in the Galactic Center region through radio spectroscopy. Early observations of F(2→2) OH absorption (Robinson et al. 1964; Goldstein et al. 1964) suggested the existence of copious molecular material within 500 pc of the Galactic Center. This was confirmed by detection of extensive (J = 1→0) ^{12}CO emission (Bania 1977; Liszt & Burton 1978). Subsequent CO surveys (Bitran 1987; Stark et al. 1988; Oka et al. 1998; Bitran et al. 1997) have measured this emission with improving coverage and resolution.

As prelude to further study of the Galactic Center molecular gas, we would like to determine its physical state—temperature and density. This involves understanding radiative transfer in CO, the primary tracer of molecular gas. Also useful is an understanding of the atomic carbon lines, [CI], since they trace the more diffuse molecular regions, where CO is destroyed by UV radiation but H_2 is still present. Using the AST/RO telescope, we conducted a detailed survey toward the inner 3 degrees of the galactic center region in ^{12}CO (J = 4→3), ^{12}CO (J = 7→6) and [CI] ($^3P_1 \rightarrow {}^3P_0$). Analyzing our data in conjunction with (J = 1→0) ^{12}CO and ^{13}CO data previously observed with the Bell Laboratories 7-m antenna, we calculated the molecular gas density as a function of position and velocity using the varying value of $T^{12}_{7\rightarrow6}/T^{12}_{4\rightarrow3}$ and an estimate of $\tau^{12}_{1\rightarrow0}$.

OBSERVATIONS

The observations were performed during the austral winter seasons of 2001 and 2002 at the Antarctic Submillimeter Telescope and Remote Observatory (AST/RO), located at 2847m at the Amundsen-Scott South Pole Station. This site has very low water vapor, high atmospheric stability and a thin troposphere making it exceptionally good for submillimeter observations. AST/RO is a 1.7m diameter, offset Gregorian telescope capable of observing at wavelengths between 200 μm and 1.3 mm (Stark et al. 2001). A dual-channel SIS waveguide receiver (Walker et al. 1992; Honingh et al. 1997) was used for simultaneous 461–492 GHz and 807 GHz observations, with double-sideband noise temperatures of 320–390 K and 1050–1190 K, respectively. Telescope efficiency, η, estimated using moon scans, skydips, and measurements of the beam edge taper, was 81% at 461–492 GHz and 71% at 807 GHz. Atmosphere-corrected system temperatures ranged from 700 to 4000 K at 461–492 GHz and 9000 to 75,000 K at 807 GHz.



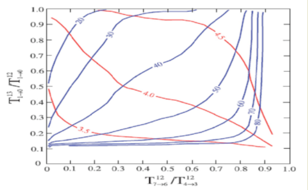


Emission from the CO (J = 4→3) and CO (J = 7→6) lines at 461.041 GHz and 806.652 GHz, together with the [CI] ($^3P_1 \rightarrow {}^3P_0$) and [CI] ($^3P_2 \rightarrow {}^3P_1$) lines at 492.262 GHz and 809.342 GHz, was imaged over the Galactic Center region $-1.3° < \ell < 2°$, $-0.3° < b < 0.2°$ with 0.5' spacing in ℓ and b; i.e., at somewhat less than half-beamwidth pointing separations. Smaller selected areas were also observed with longer integration times in the [CI] ($^3P_1 \rightarrow {}^3P_0$) line. Peak pointing errors were 1', and the beam sizes (FWHM) were 103–109'' at 461–492 GHz and 58'' at 807 GHz (Stark et al. 2001). A multiple position-switching mode was used, with emission-free reference positions chosen at least 600 from regions of interest. The standard chopper wheel calibration technique was employed, implemented at AST/RO by way of regular (every few minutes) observations of the sky and two blackbody loads of known temperature (Stark et al. 2001). The data in this survey were reduced using the COMB data reduction package.

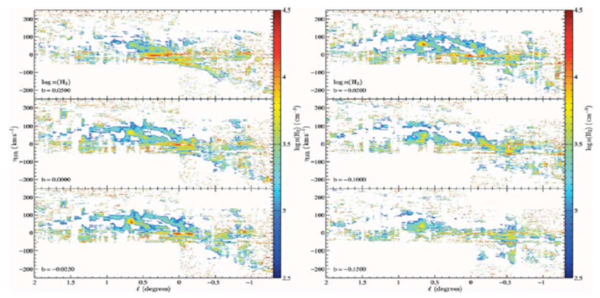
LARGE VELOCITY GRADIENT MODEL and COLUMN DENSITIES

We use the LVG methodology (Goldreich & Kwan 1974) which simplifies radiative transfer analysis of molecular lines to estimate the number density of molecular hydrogen, $n(H_2)$, throughout the Galactic center region. Due to the high velocity dispersions characteristic of the Galactic center, the LVG approximation is most likely valid over much of the mapped region.

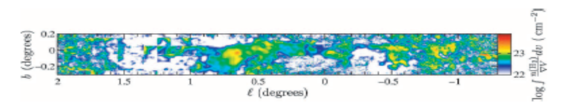
For each observed point, we take the brightness temperature ratios $T^{12}_{7\rightarrow6}/T^{12}_{4\rightarrow3}$ and $T^{13}_{1\rightarrow0}/T^{12}_{1\rightarrow0}$, to determine T_{kin} and $n(H_2)$. Results can be seen from the following figures.



Approximate representation of the relation between the line ratios and T_{kin} (blue curves, units are K) and $n(H_2)$ (red curves, units are $\log[n(H_2)/1.0\ cm^{-3}]$) generated by our LVG model, which uses an abundance ratio $^{12}CO/^{13}CO = 24$ and $X(CO)/dV = 10^{-4.5}$ pc km^{-1} s.



False color longitude–velocity maps of log $n(H_2)$ as determined by the LVG model. Regions in white indicate areas where either spectral line data are not available or the LVG model did not converge. Each of the 6 panels displays $n(H_2)$ at a different value of galactic latitude, indicated in the lower left corner of each panel.



False color velocity-channel map of $\log[\int n(H_2) dv/dV]$. $n(H_2)$ is integrated over the ranges $-150 < v_{LSR} < -60$ kms^{-1} and $20 < v_{LSR} < 150$ kms^{-1} in order to avoid contamination by the foreground material for which the LVG analysis is invalid. This value is then divided by dV in order to make a map comparable to the expected column density in units of cm^{-2}.

CONCLUSIONS

For each observed point, $T^{12}_{7\rightarrow6}/T^{12}_{4\rightarrow3}$ line ratios, together with $T^{13}_{1\rightarrow0}/T^{12}_{1\rightarrow0}$ line ratios, were used to estimate molecular hydrogen volume densities. Molecular hydrogen densities, $n(H_2)$, ranged up to the limit of our ability to determine via our LVG analysis, ~ $10^{4.5}$ cm^{-3}.

Typical gas pressures in the Galactic center gas are $n(H_2) \cdot T_{kin}$ ~ $10^{5.2}$ K cm^{-3}, while typical virial pressures are $n(H_2) \cdot T_{virial}$ ~ $10^{6.8}$ K cm^{-3}. These values can be compared to the typical gas pressures in molecular clouds near the Sun ~ $10^{3.4}$ K cm^{-3}, the typical virial pressure in molecular clouds near the Sun ~ 10^5 K cm^{-3}, and the ambient pressure of the interstellar medium near the Sun ~ 10^4 K cm^{-3} (Dickey & Lockman 1990).

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