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High Altitude Molecular Clouds: Properties

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We describe ^{12}CO observations and morphology of a new population of diffuse molecular clouds found far away from the Galactic plane These high altitude clouds (HACs) are drawn from a sample of 23 clouds identified by Malhotra(1994) as being more than 2.6 scale heights away from the plane. Since these clouds are at tangent point velocities we know their distances and height above the plane. New observations were carried out in the winter of 1994-95 with the 7 meter telescope at Bell Laboratories to map these clouds to a noise level of 0.15 K. These observations show that HACs are large - comparable in size to GMC complexes; and arranged in complexes with complicated velocity structure. The HACs have much weaker CO emission than do GMCs, and are not gravitationally bound.

INTRODUCTION

The recent discovery of molecular gas and clouds far from the Galactic plane, (Malhotra 1994, Dame & Thaddeus 1994) raises questions about the origin of these clouds and their possible role in the lifecycle of various phases of the ISM. Further study of the properties of this phase of the interstellar medium may provide some of the answers.

High altitude clouds (HACs) were originally identified as outliers in the z-distribution of ^{12}CO($1 \rightarrow 0$) emission at tangent points in the ^{12}CO survey of the first Galactic quadrant by Knapp, Stark & Wilson (1985). At the tangent points, the distances to the clouds are known, making it possible to determine their sizes. Since this survey consisted of galactic latitude slices at various longitudes, the sizes of the clouds were estimated from the b cross-section of the 1.2K (3σ) contour; typical sizes of 15 kpc were found (Malhotra 1994).

OBSERVATIONS

In the winter of 1994-95 we mapped 5 of the 23 HACs in the ^{12}CO line with the Bell labs 7m telescope to get the l-b extent and morphology at fainter levels. Typical noise levels achieved were $T_{rms} = 0.15$ K. The clouds were found to be much larger at $T = 0.5K$ brightness levels than previously measured at $T = 1.2K$, with diameters of $\sim 100pc$. For example, clouds HAC1 and HAC2, which are about 0.5° apart, were found to be part of the same complex.

PROPERTIES

The morphologies of the clouds observed so far are very different (Figure 1). HAC1-2 seems to be a complex of molecular clouds with the central velocity of the cloud changing fairly substantially over the length of the cloud. HAC12 is part of a larger structure which is not yet fully mapped. HAC21 seems centrally concentrated and adheres more to the conventional cloud image than others. HAC23 is filamentary.

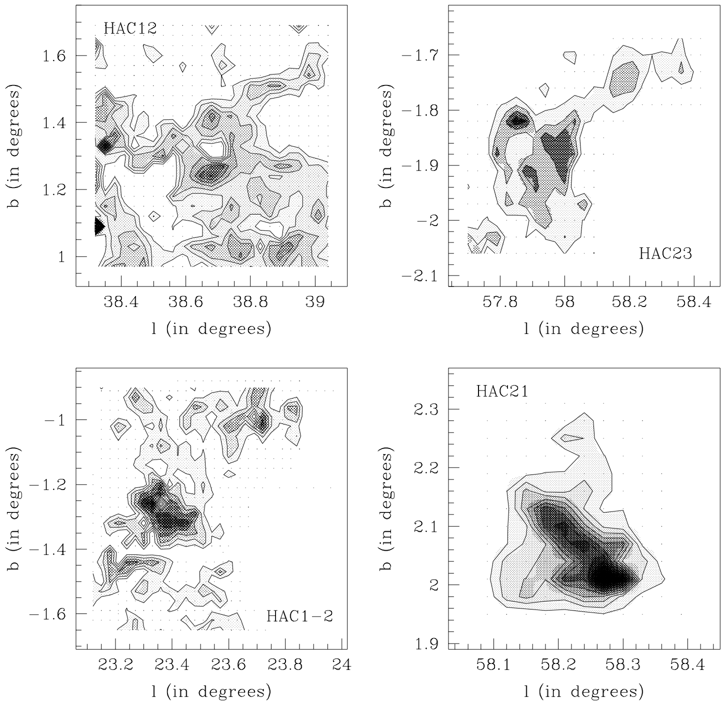

Figure 1: Morphology of some of the HACs. The peak antenna temperature is plotted as a function of Galactic latitude and longitude at contour levels of $T_A = 0.5 - 3\,\mathrm{K}$ in steps of 0.5 K.

Using the standard conversion factor $X = N(\mathrm{H}_2)/I(CO) = 3\times10^{20} cm^{-2}\,\mathrm{K}^{-1}\,\mathrm{km\,s^{-1}}^{-1}$, and the tangent point distance to the clouds, we calculate the size, mass, velocity dispersion, and the density of molecular gas. Table 1 lists these quantities for the five observed HACs.

These clouds are seen to be big (15-100 pc). The ^{12}CO emission is at very faint levels 0.5-3 K. There may be yet fainter emission which we do not detect at present. Two clouds HAC1 and HAC2 are now seen to belong to one cloud/cloud-complex whose diameter is more than 95 pc (Figure 2).

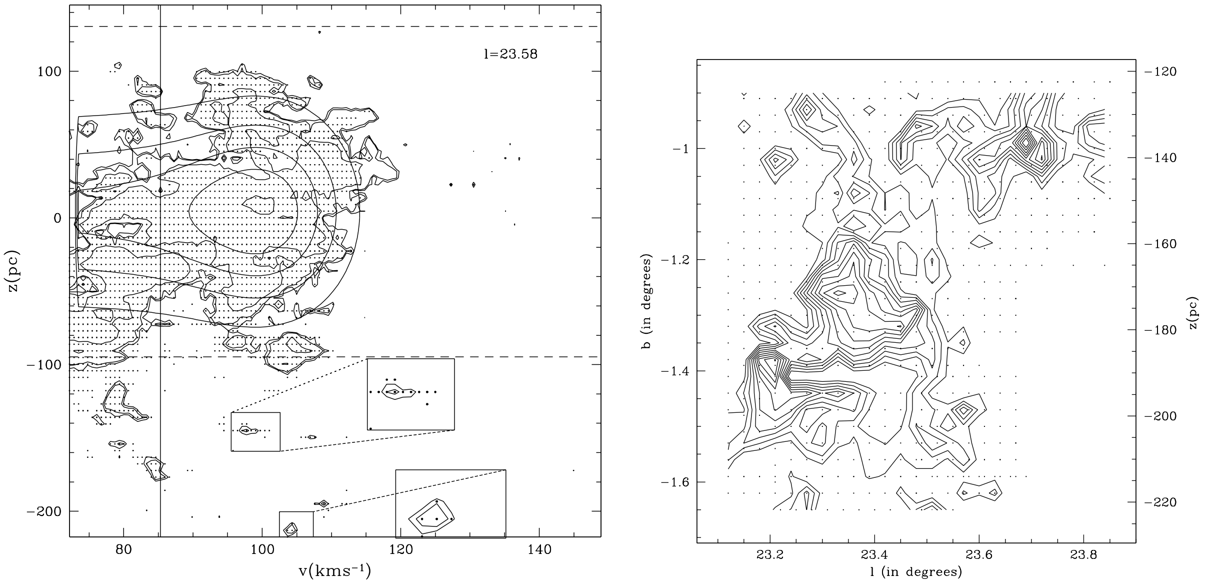

Figure 2:(a) High Altitude Clouds 1 & 2 as identified in the Knapp, Stark & Wilson (1985) survey: Contours of equal antenna temperature are plotted as a function of latitude-velocity at $l = 23.58°$. HAC1 and HAC2 are identified. (b) Contours of peak antenna temperature as a function of Galactic latitude and longitude. HAC1 and HAC2 are seen to be part of a large ($\simeq 95\,\mathrm{pc}$) and faint ($T_A = 0.5 - 3K$) cloud complex.

Table 1

Name	distance (kpc)	size (pc)	mass ($M_\odot$)	σ_v ($\mathrm{km\,s^{-1}}$)	$\sigma_v(virial)$ ($\mathrm{km\,s^{-1}}$)	$n_{average}$ ($\mathrm{cm^{-2}}$)
HAC1-2	7.8	95	2×10^5	9.2	1.8	6
HAC12	6.6	> 81	$> 1.8 \times 10^5$	5.3	2.5	6
HAC21	4.5	15	8.5×10^3	2.5	0.6	4
HAC23	4.5	> 55	$> 3.7 \times 10^4$	3.2	1.0	2.5

The average densities derived are $\sim 2.5 - 6\mathrm{cm}^{-3}$, a value more typical of the diffuse atomic medium than of molecular gas (Spitzer 1978). These densities are derived by assuming that the conversion factor $X = {}^{12}\mathrm{CO}/\mathrm{H}_2$ is the same for these clouds as for GMCs. This assumption might not be true for such diffuse clouds. For High Latitude Clouds, which may be local analogs of HACs, the ratio X is variable by factor of a few (Magnani et al. 1988). The size of a cloud/clump is probably smaller than the size of the complex (Figure 1) leading to a sytematic underestimate of the volume density. Models of translucent clouds show that the ^{12}CO emitting regions should be surrounded by H_2 envelopes which do not show emission in ^{12}CO (van Dishoek & Black 1988). This is because the self-shielding for H_2 happens at lower column densities than for ^{12}CO because of higher abundance of H_2 and because the UV absorption lines are narrower. Excess 100 μm emission is seen on the outskirts of High Latitude Clouds surrounding the CO emitting regions. The simplest explanation is that the dust emission is tracing total gas, and there exists H_2 at lower column densities than CO (Reach, Koo & Heiles 1994).

Observations in the $^{13}CO(1 \rightarrow 0)$ line have been made for one cloud, and show that the ratio $R = I(^{12}CO)/I(^{13}CO(1 \rightarrow 0)) \simeq 9$ is higher for the HACs (Malhotra 1994) than for the Galactic plane clouds where R=3-6 (Gordon & Burton 1976), as expected for diffuse clouds.

The velocity dispersion (σ_v) of the clouds is calculated as a intensity weighted mean of the velocity dispersion at each point. This is smaller than the velocity dispersion of the average profile of the cloud, because it removes the velocity gradients across the cloud. σ_v is greater than the virial velocity dispersion by a factor of > 2.5. In addition these clouds are observed to have a very faint high velocity dispersion ($\simeq 15 - 30\,\mathrm{km\,s^{-1}}$) component on their outskirts (Figure 3). The peak brightness of this component is $< 0.5\,\mathrm{K}$. The faint high velocity gas can be an indication that the cloud is evaporating or of outflows associated with young stellar objects, which appear faint because they are much smaller than the beam-size. The spatial distribution of the high velocity dispersion gas, and the unboundedness of the clouds somewhat favors the former hypothesis.

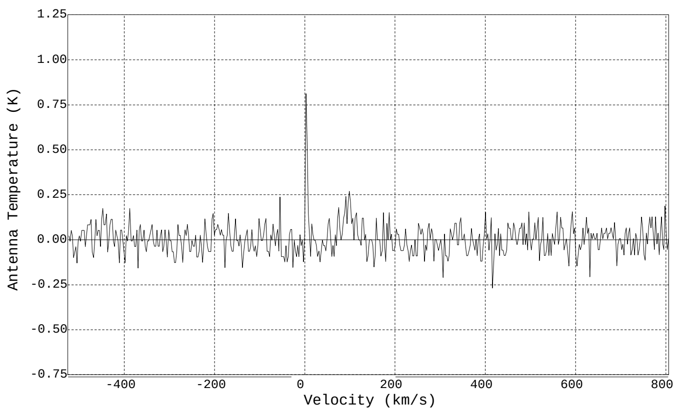

Figure 3: The broad velocity component near the tangent point velocity ($v \simeq 97\,\mathrm{km\,s^{-1}}$) is associated with HAC1-2 and has a velocity dispersion of $22 \pm 5\,\mathrm{km\,s^{-1}}$ and peak temperature of 0.2 K

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