Resolving the Near-Far Kinematic Distance Ambiguity

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Abstract

We have analyzed the first ten square degrees of the Boston University-Five College Radio Astronomy Observatory Galactic Ring Survey (GRS), a new, fully-sampled survey of ^{13}CO emission over a large portion of the inner Galaxy. We compare the GRS ^{13}CO maps to 21 cm H I maps from the Boston University-Arecibo Observatory Galactic H I Survey. Toward many molecular clouds, we find a remarkable association between ^{13}CO emission and H I self-absorption, both in velocity and morphology. In particular, G45.6+0.3, a large filamentary cloud, shows deep H I self-absorption thoughout the ^{13}CO emitting region. This cloud is also associated with pronounced optical extinction and thus lies at the near kinematic distance.

Position-velocity diagrams also show a number of additional molecular clouds that correspond with H I self-absorption.

Photodissociation theory suggests that the skins of typical molecular clouds exposed to normal Galactic UV radiation fields will exhibit H I self-absorption against strong H I backgrounds. Because H I emission is ubiquitous throughout the Galaxy, with sufficient angular resolution, the cold H I can be used to determine whether the molecular cloud lies at the near or far kinematic distance. Clouds at the near distance will show H I self-absorption, whereas clouds at the far distance will show H I in emission. This technique can resolve the kinematic distance ambiguity by cleanly separating near clouds from far clouds.

Introduction

We compare the GRS ^{13}CO molecular data and 21 cm H I data taken from the Boston University-Arecibo Observatory (BUAO) Galactic H I Survey. The BUAO Survey parameters are:

Table 1: BUAO Galactic H I Survey Parameters.

Galactic Longitude	30.5 to 60.5 degrees
Galactic Latitude	-0.5 to 0.5 degrees
Angular resolution	$4'$ HPBW
Angular sampling	$2'$ or $4'$ intervals
LSR velocity range	-264.0 to $+264.0$ km s^{-1}
Velocity resolution	0.52 km s^{-1}
Sensitivity	0.5 K

In the course of this comparison, we found that a number of clouds show a clear correspondence between ^{13}CO emission and H I self-absorption, both in morphology and in velocity. Although H I self-absorption toward molecular clouds has been known for some time, this is the first clear correspondence between H I self-absorption and CO emission in both 2-dimensional morphology and in velocity. This correspondence suggests that these molecular clouds contain significant amounts of cold atomic hydrogen.

Breaking the Near-Far Kinematic Distance Ambiguity

As a special consequence of the geometry of the inner Galaxy, any particular value of radial velocity corresponds to two distances along the line of sight, called the "near" and "far" distances. Thus, kinematic information alone cannot establish a reliable distance estimate, due to this so-called "distance ambiguity."

The likelihood of detecting H I self-absorption, however, favors the geometry in which a molecular cloud lies at the near kinematic distance. Since H I is ubiquitous throughout the Galaxy, warm H I emits at essentially every velocity. For clouds at the near kinematic distance, there is an ample amount of H I at the far distance against which a cold molecular foreground cloud can be seen in silhouette. If the same cloud were placed at the far distance, there would be very little background H I, and the self-absorption feature would be absent. Even if a "far" molecular cloud were to have H I self-absorption, it would not be observed since its characteristic spectral signature would be filled in by emission from H I at the foreground near position. The geometry is illustrated in a face-on sketch of the Inner Galaxy in Fig. 1.

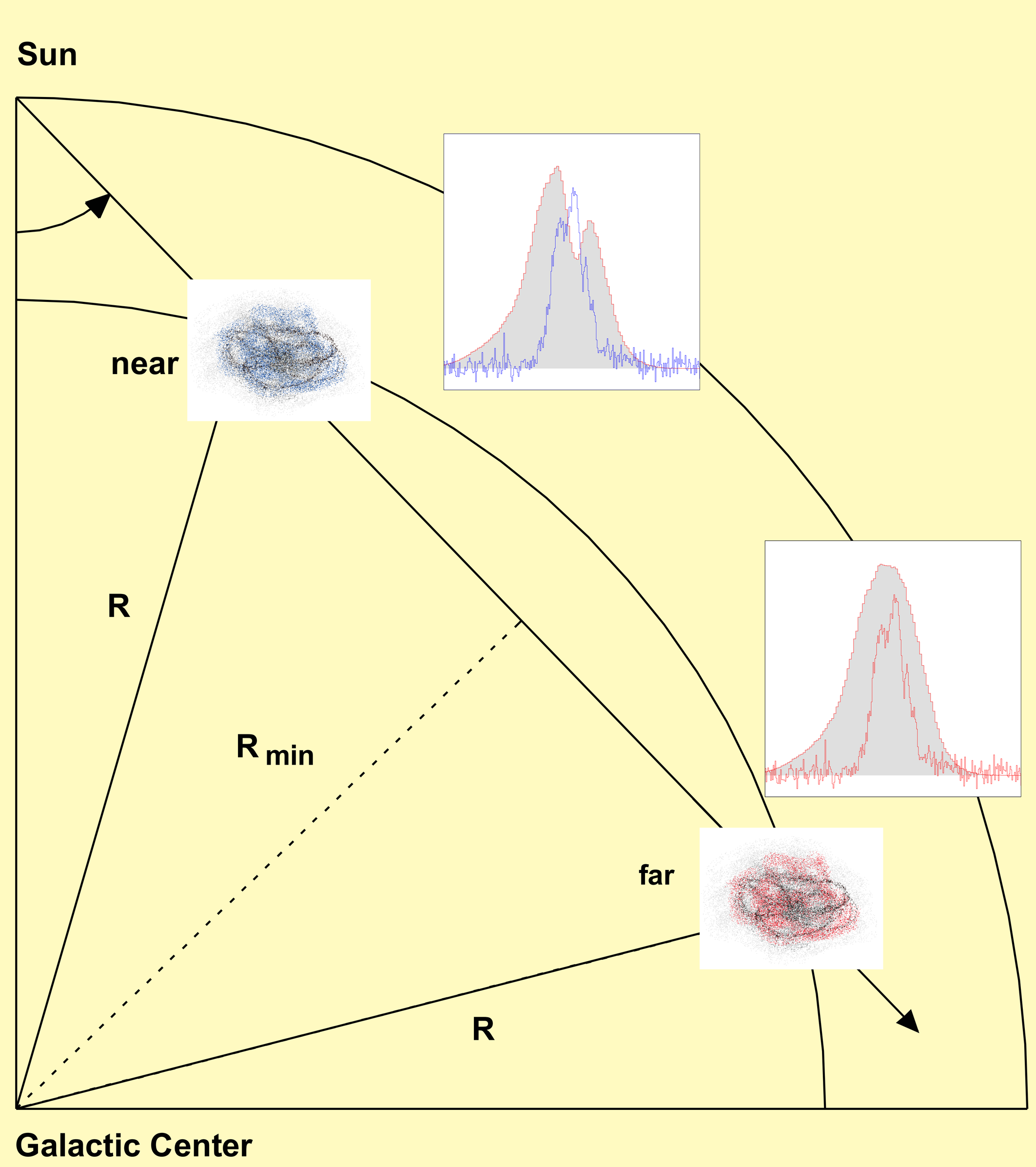

Fig. 1: *Face-on sketch of the geometry of HI self-absorption in the First Quadrant of the Milky Way. Statistically, only HI associated with molecular clouds located at the near kinematic distance will show the characteristic spectral signature of HI self-absorption. This is seen schematically in the two plots which show grey scale HI spectra with CO spectra superimposed as either red or blue line profiles.*

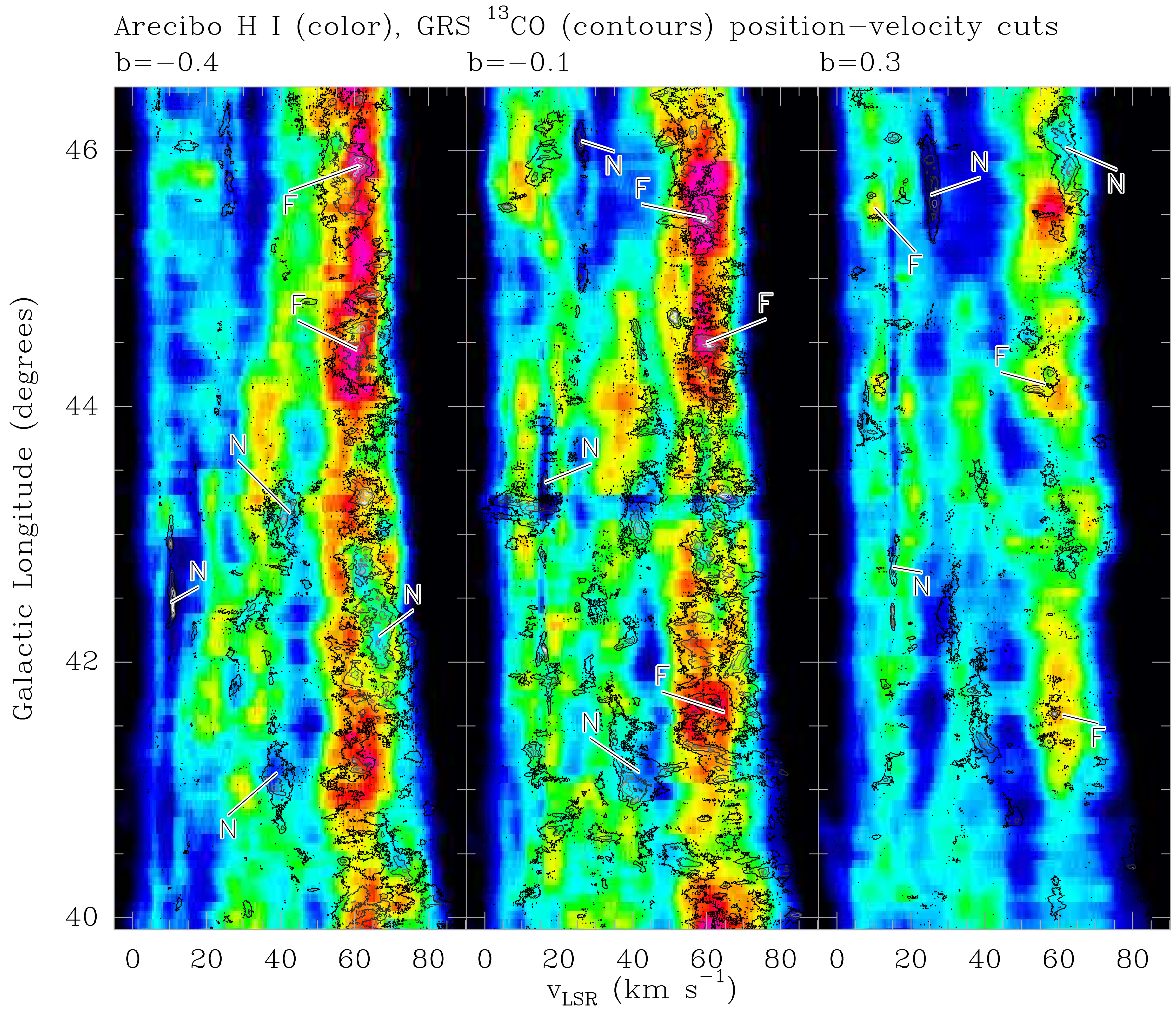

Fig. 5: *Shown is a comparison between GRS ^{13}CO and BUAO H I emission in longitude-LSR velocity space. Color indicates the H I brightness temperature distribution at three galactic latitudes for the longitude range $40^\circ < l < 46^\circ\!.3$. Red corresponds to the strongest HI emission, blue to the weakest. The GRS ^{13}CO emission distribution is drawn as black to white contours as intensities increase. It is clear that ^{13}CO features correlate both with H I peaks and H I valleys. Analysis of the H I valley spectra shows that many have the characteristic signature of H I self-absorption, indicating that the CO cloud is located at the near kinematic distance. CO clouds associated with H I peaks are located at the far kinematic distance (see Figs. 1 through 4). Based on H I self-absorption, we indicate here with the symbols "N" and "F" whether a given ^{13}CO emission clump is located at the Near or Far kinematic distance.*

G45.6+0.3: A Case Study

The cloud with the deepest self-absorption line, G45.6+0.3, shows pronounced visual extinction, and is therefore unequivocally located at the near kinematic distance. We suggest that, since the geometry of self-absorption favors clouds located at the near kinematic distance, then the presence or absence of self-absorption may prove to be a powerful technique to resolve the near-far distance ambiguity.

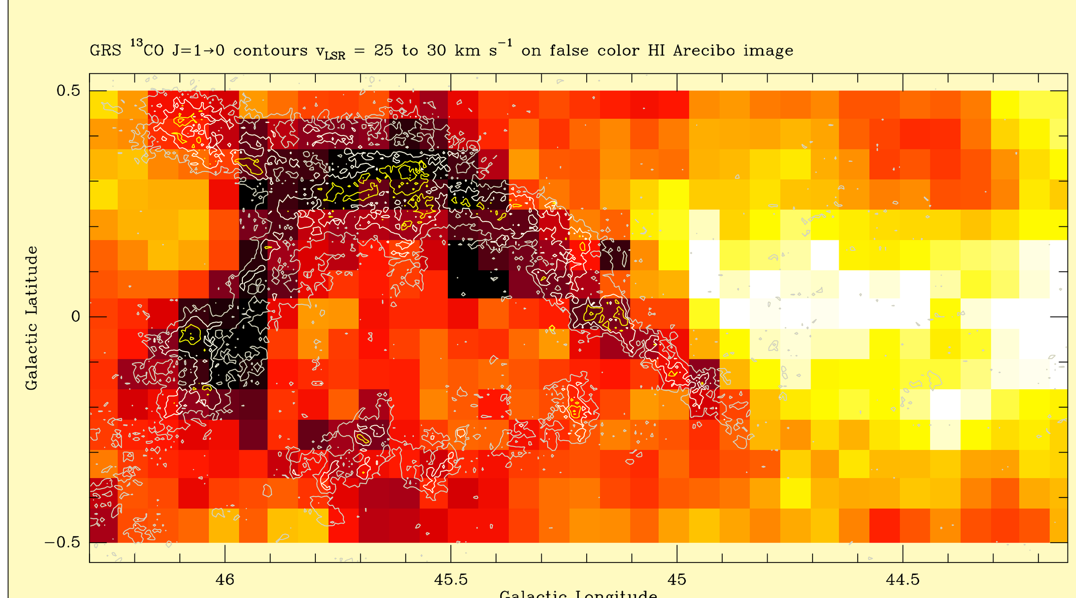

Fig. 2: *Overlay of GRS ^{13}CO J=1→0 contours towards G45.6+0.3 integrated over the velocity range 25−30 km s^{-1} on a false color image of the appropriate region from the BUAO H I Survey. Black indicates H I self-absorption. The ^{13}CO contours start at the 3σ level of the map. Higher intensity contours are drawn in yellow to emphasize the locations of peak ^{13}CO emission.*

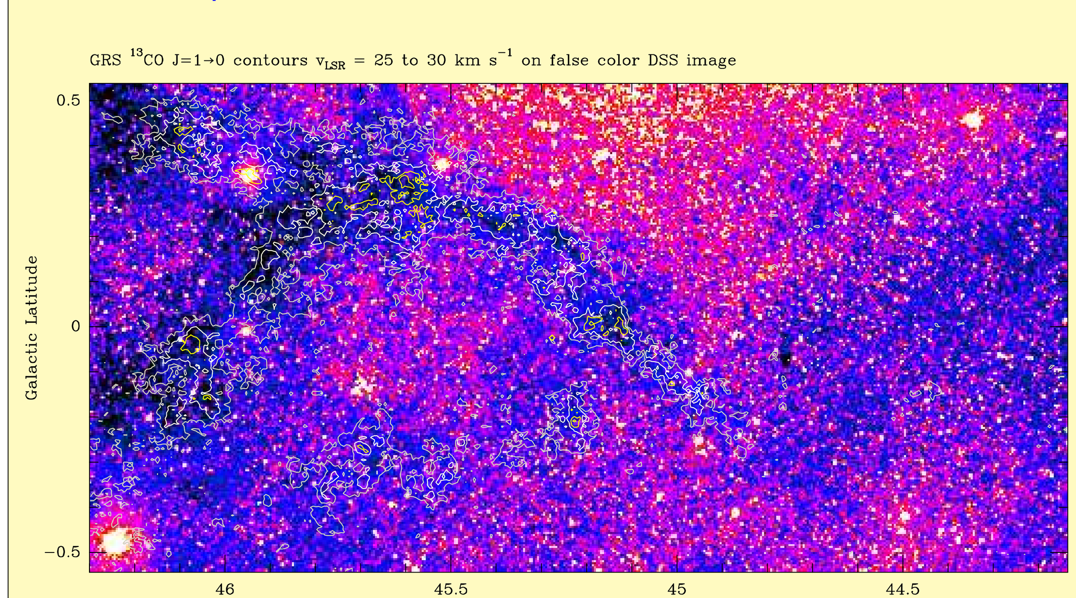

Fig. 3: *Overlay of the GRS ^{13}CO J=1→0 contours from Fig. 2 towards G45.6+0.3 on a false color optical image of the appropriate region from the POSS plate (Digital Sky Survey, DSS).*

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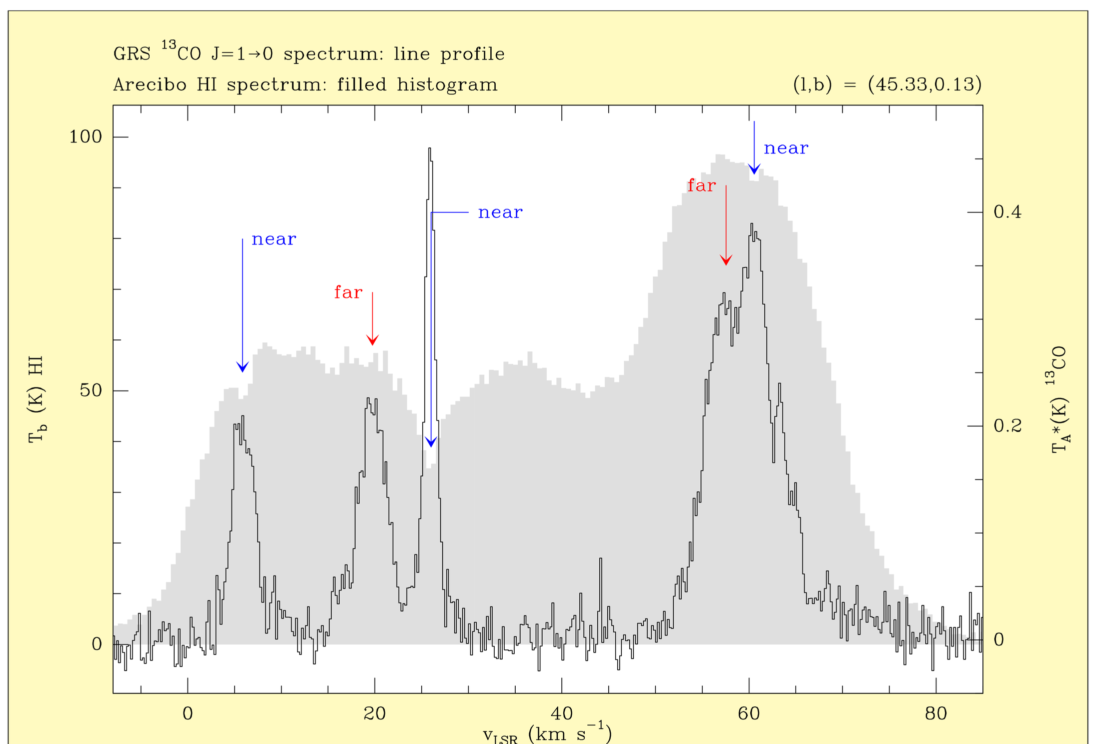

Fig. 4: *A comparison of GRS ^{13}CO J=1→0 (black line) and H I (solid gray) emission towards a selected position in G45.6+0.3. To enhance the signal to noise and properly compare the data sets, the ^{13}CO data have been resampled to the H I resolution and grid ($4'$). The presence (or absence) of H I self-absorption at the ^{13}CO velocity places the cloud at the near (or far) kinematic distance.*

Conclusions

In comparing the ^{13}CO Galactic Ring Suvey with the BUAO H I survey, we have found that many molecular clouds exhibit both ^{13}CO emission and H I self-absorption. We conclude the following:

- H I self-absorption matches the spatial extent, velocity, and linewidth of ^{13}CO emission for the molecular cloud G45.6+0.3. Visual extinction confirms that this cloud lies at the near kinematic distance.
- The theory of photodissociation regions suggests that cold H I is associated with typical molecular clouds ($n \sim 10^3$ cm^{-2}, $\chi \sim 1$ Habing fields). This cold H I will have sufficient opacity to exhibit self-absorption if the cloud lies in front of typical H I backgrounds.
- The geometry of the Inner Galaxy suggests that the presence or absence of H I self-absorption toward a molecular cloud depends on whether it lies at the near or far kinematic distance. Thus, the distances to molecular clouds in the Inner Galaxy can be well determined.
- Position-velocity diagrams show a large number of molecular clouds with H I self-absorption. We conclude that these clouds lie at the near distance as well. The clouds that do not show H I self-absorption lie at the far kinematic distance. We can thus use this technnique to produce an accurate map of the molecular gas distribution in the Milky Way.