Neutral Hydrogen Self-Absorption Features in the Canadian Galactic Plane Survey

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Abstract. We have begun a systematic study of cold HI within the $73^\circ \times 9^\circ$ 21cm coverage of the Canadian Galactic Plane Survey (CGPS; Taylor et al. 1998). The $\sim 1'$ beam of the CGPS reveals considerable substructure within detected clouds. Our investigation has uncovered a wealth of remarkable features in both the Local and Perseus Arms. Some of these have clear counterparts in ^{12}CO and far-IR dust emission, while others are only visible in 21cm absorption, often at extremely low contrast. All display a mix of clumpy and filamentary morphologies. We present examples below and discuss their physical properties.

1. Cold Atomic Gas Features

HI self-absorption (HISA) against background HI emission reveals cold atomic gas structures in the interstellar medium. These often display a significant correlation with tracers of molecular gas and dust (e.g., Knapp 1974; Peters & Bash 1987), though certainly not always; the exact physical relationship between HISA and H_2 is not well known. HISA features as a group are poorly understood, due to the high angular resolution required for accurate estimates of background spectra from adjacent sightlines, and to the lack of any unbiased high-resolution searches for such objects. Our $\sim 1'$ beam survey unveils a new and detailed view of HISA in the outer Galaxy.

Figure 1 shows a particularly rich area near the Galactic plane. This CGPS 21cm channel map contains a plethora of complex HISA features, ranging in morphology from knotlike condensations to extended filaments. Many have cor-

Figure 1. Numerous HISA features in the Perseus Spiral Arm over several square degrees. CGPS HI 21cm line intensity ranges from 75 K (black) to 135 K (white). White ^{12}CO $J = 1 - 0$ emission contours are for 1, 3, & 5 K (Heyer et al. 1998).

responding ^{12}CO $J = 1–0$ emission in the survey of Heyer et al. (1998). Of those that do not, some are highly opaque while others are nearly transparent. The HISA-H_2 relation is clearly not a simple correlation. Discovering the underlying reasons for the large scatter in the N_{H_2}/N_{HISA} ratio is a major goal of our study, given its ramifications for our understanding of the phase structure and evolution of the interstellar medium.

Channel maps and spectra for two particular HISA features are given in Figure 2. The first object is selected from the field shown in Figure 1. Here 60 μm dust emission contours from Cao et al. (1997) have been added to show the frequent agreement between HISA, H_2, and dust. In some locations the dust appears to trace the HISA better than ^{12}CO, though in several areas neither is a good match. The HISA feature at the center of the image is quite prominent in ON and OFF spectra taken from the marked boxes, with an excellent velocity match in ^{12}CO.

The second object in Figure 2 lies in the Local rather than the Perseus Arm. Its contrast is very weak, and no far-infrared counterpart is apparent. However, though this feature lies beyond the longitude range of Heyer et al. (1998), a reasonable ^{12}CO match is found in the $\sim 1^\circ$ resolution composite survey of Dame et al. (1987). A handful of similarly faint local features, together with many others at Pereus Arm velocities, suggests the cold atomic structures revealed in HISA may exist nearly everywhere, but are only detectable under suitable viewing conditions.

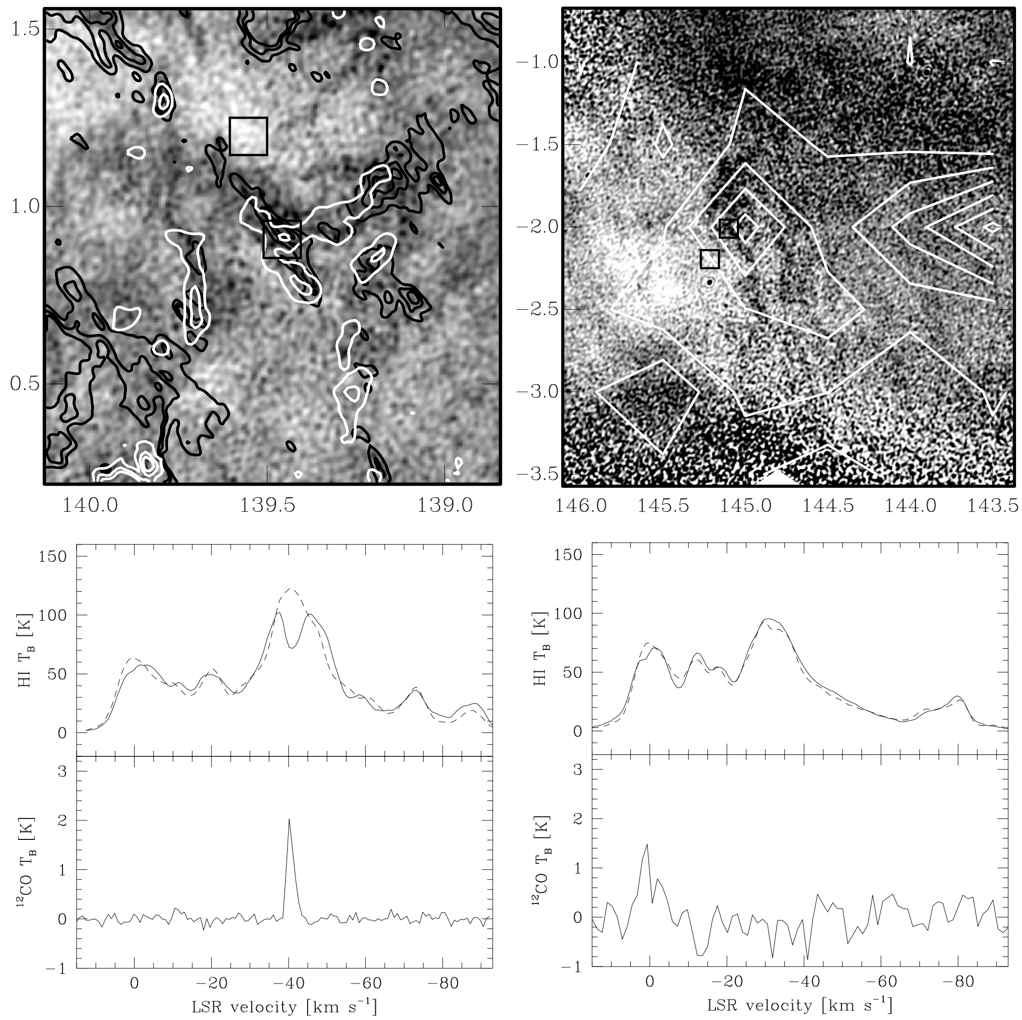

Figure 2. Selected HISA features in the Perseus Arm at -41 km s^{-1} (left) and in the Local Arm at $+1$ km s^{-1} (right). *Top:* HI 21cm line brightness temperatures, increasing from black to white, with ranges 50-135 K (left) and 55-80 K (right); coordinates are Galactic. White ^{12}CO $J = 1 - 0$ line emission contours are for 1, 3, & 5 K (left; Heyer et al. 1998) and 0.33, 0.67, 1.0, and 1.33 K (right; Dame et al. 1987). Black 60μm dust emission contours are for 15, 17, & 19 MJy sr^{-1} (left; Cao et al. 1997); no correspondence was found for the local feature. *Bottom:* spectra show HI at ON and OFF boxes marked on maps, and ^{12}CO at the ON position.

2. Physical Properties

We wish to measure, or at least place useful limits on, the physical parameters of HISA objects in the CGPS dataset: optical depth τ_{HISA}, spin temperature T_S, column and volume densities N_{HISA} and n_{HISA}, and mass M_{HISA}. Obtaining these requires a solution to the radiative transfer equation. We consider the implicit 4-component formulation of Feldt (1993), with a HISA feature, warm, optically thin HI emission in front of and behind it, and a continuum background T_C:

$$T_{ON} \;=\; T_{OFF} \;+\; (T_S - p \cdot T_{OFF} - T_C) \cdot (1 - e^{-\tau_{HISA}}) \;.$$

Here T_{ON} and T_{OFF} represent the continuum-subtracted ON and OFF brightnesses shown in Figure 2, and p is the fraction of T_{OFF} emission lying behind the HISA feature. Constraining p is often difficult, but if possible, leaves the two unknowns, τ_{HISA} and T_S. Here other relations can be of help. Spin and kinetic temperatures are similar in cold gas, and a Gaussian line center has $\tau_0 = (5.2 \times 10^{-19} \cdot N_H[\mathrm{cm}^{-2}]) \;/\; (\Delta v_{FWHM}[\mathrm{km\,s}^{-1}] \cdot T_S[\mathrm{K}])$. Assumptions of uniform gas density and an ideal gas law then produce the transcendental equation

$$T_S = \sqrt{\frac{5.2 \times 10^{-19} \cdot L_{\|} \cdot P/k}{\Delta v_{FWHM} \cdot \left(-\ln \left[\frac{T_S + (1-p) \cdot T_{OFF} - (T_{ON} + T_C)}{T_S + (1-p) \cdot T_{OFF} - (T_{OFF} + T_C)} \right] \right)}} \;,$$

where $L_{\|}$ is the HISA line-of-sight pathlength, and a canonical pressure such as $P/k = 4000$ cm^{-3} K is used (only thermal pressure is relevant).

$T_C = 5$ K for the objects in Figure 2, and we assume cylindrical filaments to obtain $L_{\|}$. A distance of ~ 2 kpc for the Perseus feature then implies $T_S \sim 70$ K, $\tau_{HISA} \sim 1$, $N_{HISA} \sim 5 \times 10^{20}$ cm^{-2}, $n_{HISA} \sim 55$ cm^{-3}, and $M_{HISA} \sim 700$ M$_\odot$. For the local gas we can only estimate $d \sim 100 - 1000$ pc (beyond the Local Bubble), yielding $T_S \sim 55 - 65$ K, $\tau_{HISA} \sim 0.2 - 1.8$, $N_{HISA} \sim 7 \times 10^{19} - 7 \times 10^{20}$ cm^{-2}, $n_{HISA} \sim 73 - 62$ cm^{-3}, and $M_{HISA} \sim 2 - 200$ M$_\odot$. $p = 1$ was used in both cases; unphysical solutions result for $p < 0.8$.

Though our methods of estimating distances and background spectra are still crude at this stage, the values obtained serve as useful rough measures of the class of cold atomic structures revealed by our ongoing investigation.

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