TRIGGERED STAR FORMATION IN A TURBULENT ISM
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Cold H I in Turbulent Eddies and Galactic Spiral Shocks

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Abstract. H I 21cm-line self-absorption (HISA) reveals the shape and distribution of cold atomic clouds in the Galactic disk. Many of these clouds lack corresponding CO emission, despite being colder than purely atomic gas in equilibrium models. HISA requires background line emission at the same velocity, hence mechanisms that can produce such backgrounds. Weak, small-scale, and widespread absorption is likely to arise from turbulent eddies, while strong, large-scale absorption appears organized in cloud complexes along spiral arm shocks. In the latter, the gas may be evolving from an atomic to a molecular state prior to star formation, which would account for the incomplete HISA-CO agreement.

Keywords. radiative transfer, surveys, ISM: clouds, ISM: evolution, ISM: kinematics and dynamics, ISM: structure, Galaxy: structure, radio lines: ISM

1. Imaging the Cold Atomic Medium

Cold atomic gas contains a large fraction of the mass of the interstellar medium (ISM) and is a critical precursor to molecular cloud formation. However, this "cold atomic medium" is hard to map in isolation, since warmer gas is often brighter in traditional H I 21cm-line emission observations. Fortunately, with proper angular resolution, cold atomic clouds can be imaged as H I self-absorption (HISA) against warmer background H I emission (Gibson et al. 2000). Recent large-scale radio synthesis surveys like the Canadian and VLA Galactic plane surveys (CGPS: Taylor et al. 2003; VGPS: Stil et al. 2006) are both well suited to HISA studies.

Figure 1 compares some sample CGPS HISA to CO emission. The intricate structure of the HISA clouds is clear, as is their frequent lack of apparent CO. This lack is a puzzle unless significant H_2 is present without CO, since the low temperatures of many HISA features ($T < 50$ K) are hard to explain without molecular gas. But if these clouds are evolving rather than stable objects, then perhaps many have not yet formed enough CO to detect (e.g., Klaassen et al. 2005).

Using an algorithm to identify and extract HISA features in the H I data, we recently published a HISA census of the $73° \times 9°$ area covered by the first 5 years of the CGPS (Gibson et al. 2005). As shown in **Figure 2**, a low-level froth of weak, disorganized HISA is found throughout the regions of the CGPS where the background emission is bright enough for the HISA to be reliably detected. By contrast, stronger absorption is organized into discrete clouds and complexes.

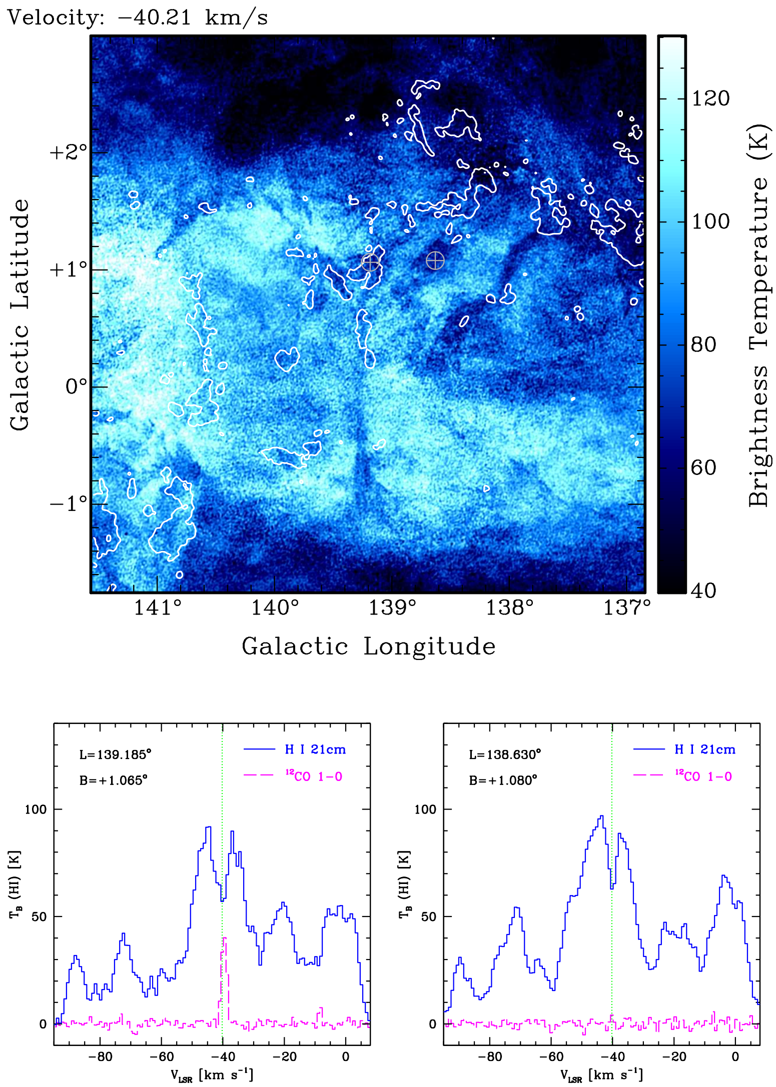

Figure 1. Sample HISA in the CGPS. The upper panel shows an H I channel map with ^{12}CO 1-0 contours from Heyer et al. (1998); the LSR velocity places this gas in the Perseus spiral arm some 2 kpc away. H I and CO spectra at the two marked positions are plotted in the lower panels, showing that HISA is found with and without CO, with the latter case more common in the outer Galaxy.

2. Velocity Perturbation Mechanisms

HISA requires background line emission at the same radial velocity as the foreground cloud. Consequently, HISA radiative transfer probes both the temperature and the velocity field of Galactic H I. The CGPS is primarily in the outer Galaxy, where pure differential rotation allows only one position along the line of sight to have a particular velocity. Since we detect HISA in the outer Galaxy, the real velocity field must be per-

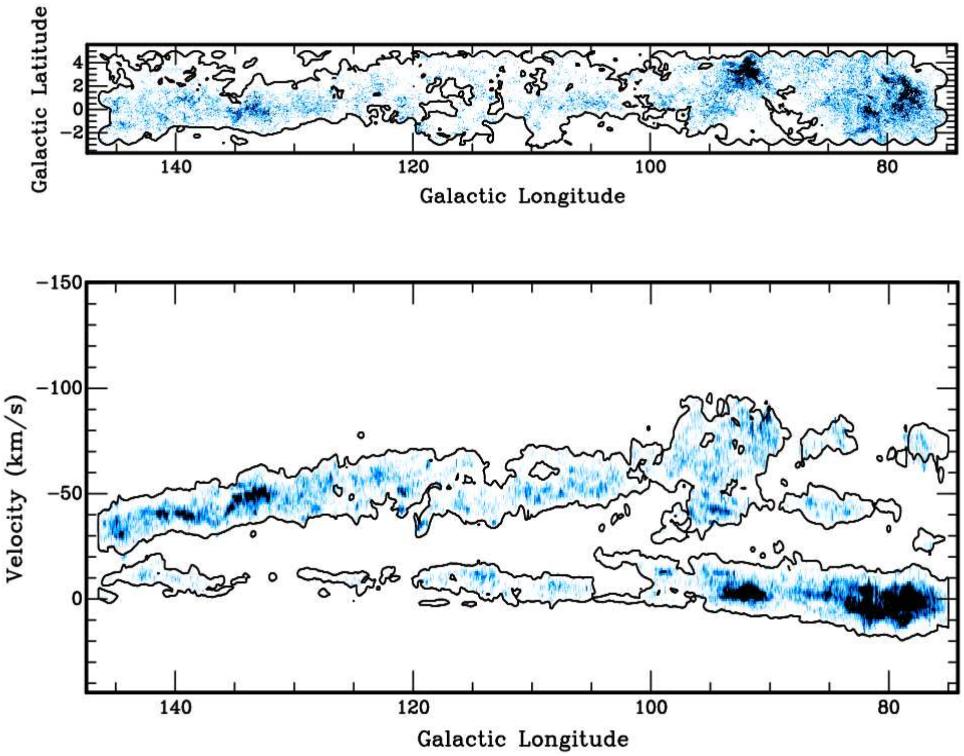

Figure 2. Longitude-latitude and longitude-velocity maps of HISA extracted from the initial $73^\circ \times 9^\circ$ portion of the CGPS, in which the HISA ON-OFF absorption amplitude is integrated over velocity (top) and latitude (bottom), with stronger absorption being darker. Contours mark where the H I emission background becomes too faint for reliable HISA detection.

turbed from this simple rotation model to provide background fields to absorb against. Two known mechanisms for this are turbulence and spiral density waves.

The weak, widespread HISA in **Figure 2** can be explained as an ambient froth of cold atomic gas in the ISM made visible by turbulent eddies; perhaps the cold gas is even a product of convergent turbulent flows, as some models suggest (e.g., Vázquez-Semadeni et al. 2006). The stronger HISA, however, is concentrated into distinct complexes, especially along the Perseus arm near $-40\,\mathrm{km\,s^{-1}}$, arguing for a more organized mechanism for these features. The very cold temperatures implied by this strong absorption could arise from gas that is forming H_2 but has not yet formed much CO.

3. Interpreting the Galactic HISA Distribution

Figure 3 shows a new HISA survey incorporating the VGPS and extensions to the CGPS (Gibson et al. 2006). This plot includes CO contours and a curve marking the maximum velocity departure from circular rotation predicted by Roberts (1972) for the Perseus spiral shock. Apart from some irregular ISM structure Roberts did not model, the strong Perseus HISA lies near the shock curve but at less extreme velocities, consistent with clouds lying just downstream of the spiral shock. Similar but fainter shock-related HISA may be seen in the Outer arm at negative velocities in the VGPS data. Both arms have a poor HISA-CO match, as would be expected for evolving gas; in this scenario,

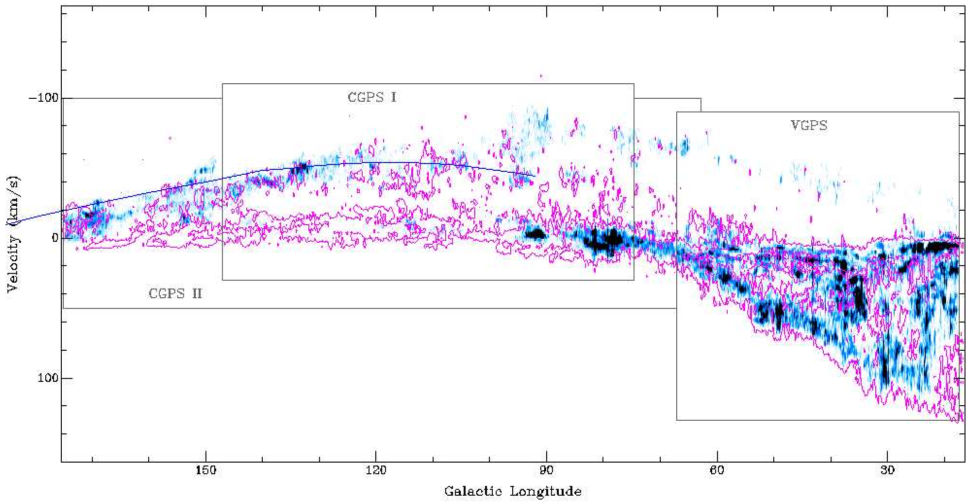

Figure 3. Longitude-velocity HISA distribution over the entire area covered by the original CGPS, the CGPS II extension, and the VGPS. Contours show molecular gas traced by Dame et al. (2001) ^{12}CO 1-0 emission, and the curved line marks the maximum velocity departure from Galactic rotation predicted by the Perseus arm spiral shock model of Roberts (1972).

the visible CO traces more evolved gas further downstream, where little background H I emission is left to show the remaining cold atomic gas in the CO clouds as HISA.

In the inner Galaxy, the picture is more complex. A much larger amount of HISA is seen, since even simple rotation provides near and far points on each sight line with the same velocity. This allows a much more widespread H I emission background, which may account for the stronger HISA-CO agreement and the lack of clearly-defined spiral arms. However, the latter requires a significant amount of cold interarm H I in the disk. Whether the interarm cold cloud population is related to the outer-Galaxy turbulent HISA population is still under investigation.

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