DARK HYDROGEN IN THE GALACTIC PLANE

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Abstract New high-resolution surveys reveal an abundance of cold H I features in the Galactic plane. These frequently trace spiral arm structure while failing to trace CO features as well as they should if the cold H I is primarily in molecular clouds.

1. The Cold H I Phase

Cold atomic hydrogen gas with $T < 10^2$ K is an important component of Galactic interstellar matter. Though it occupies only a small fraction of the ISM volume, cold H I contains $\sim$ 30% of the total gas mass near the Sun [9]. It also has abundant small-scale structure in 21cm line data, probably from turbulent and magnetic processes, and like molecular gas, it is often found in quiescent regions. The detailed relationship between cold H I and H_2 is of great interest, since classical "onion-skin" static cloud models require an association of the two phases that is not always seen [2, 11]. Evolution from one phase to the other may explain such disagreements, especially in the context of large-scale events like spiral density waves, whose structure may be probed on a Galactic scale by the radiative transfer of the 21cm line itself.

Despite its importance, cold H I is difficult to observe [3]. Its 21cm emission mixes with that of warmer gas, while its absorption against bright continuum sources is limited by their angular extents. 21cm H I self-absorption (HISA) against warm H I emission is much better for mapping cold H I, but it requires high angular resolution and broad sky coverage in order to measure the absorption properly and to chart the cloud population in an unbiased way.

2. HISA in the Galactic Plane

Detailed mapping of cold H I has become possible with the advent of the International Galactic Plane Survey, a collection of multiwavelength surveys of the ionized, atomic, and molecular gas and dust emission at arcminute scales over most of the Galactic disk. 21cm line data from the Canadian [12], Southern

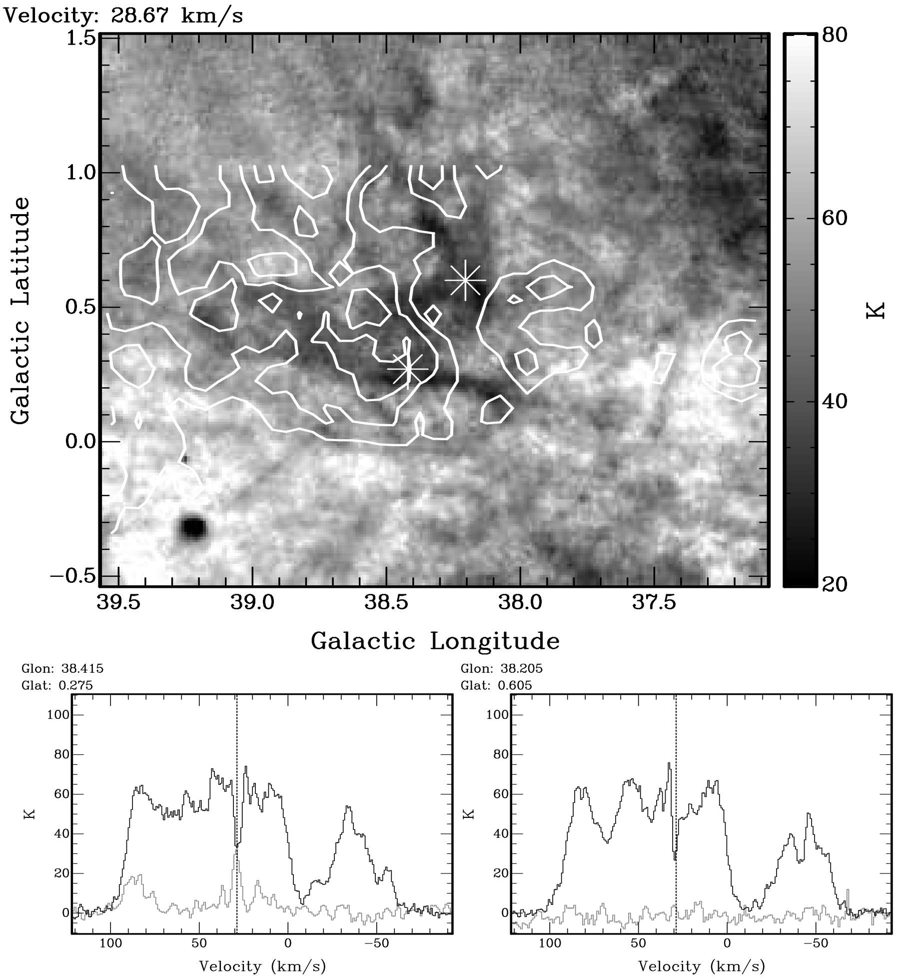

Figure 1. *Top:* VLA Galactic Plane Survey H I channel map of a fan-shaped $\sim 1^\circ$ HISA complex in the inner Galaxy. Contours show ^{12}CO $1-0$ emission [1] for $b \leq +1^\circ$ with T_b =1, 2, and 3 K. The dark spot at $\ell = 39.2^\circ, b = -0.3^\circ$ is H I absorption against the continuum source 3C 396. Two asterisks mark spectral sight lines. *Lower left:* H I and CO spectra where HISA and CO coincide. The brightness scale is for the H I, with the CO scale exactly 10% of this. The vertical line marks the map LSR velocity. *Lower right:* HISA without CO.

[8], and VLA [13] Galactic Plane Survey components of the IGPS reveal a rich and subtle population of HISA features, many of which are invisible at lower resolutions. Analyses of several CGPS and SGPS features [4, 6, 7] find H I temperatures of a few tens of Kelvins and densities of order 10^2 cm^{-3}. Some have obvious counterparts in CO emission, while others do not; this is also the case with the VGPS HISA in Figure 1. While most inner-Galaxy HISA has

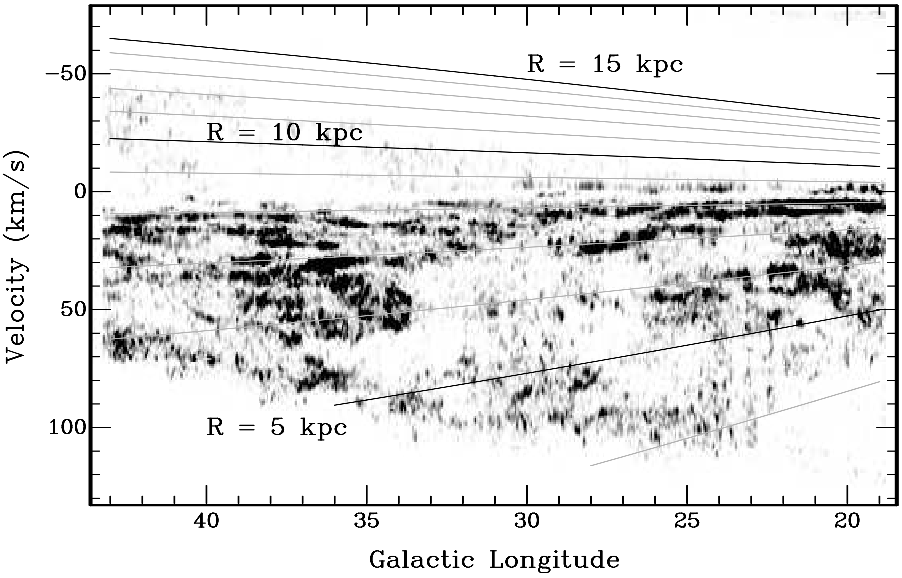

Figure 2. HISA line strength integrated over latitude for a 25° section of the VGPS, with darker features being stronger. Lines of constant Galactocentric radius R are overplotted for a flat rotation curve with $R_0 = 8.5$ kpc and $v_0 = 220\ \mathrm{km\,s^{-1}}$.

associated CO, most outer Galaxy HISA does not [3, 4, 7]. Since inner Galaxy sight lines are more likely to have the bright H I backgrounds needed for HISA, more frequent association of HISA with CO is likely in the inner Galaxy. But HISA without CO is not easy to explain: either the HISA coexists with H_2 untraced by CO, or the HISA exists outside molecular clouds, where its cold temperature is hard to reconcile with stable gas phase models.

A systematic study using algorithms to identify and analyze HISA features in the CGPS is underway [5]. Because these algorithms are sensitive only to the most obvious HISA features, which are in turn biased by the need for adequate background H I fields, they detect only a small fraction of the total cold H I mass; however, this fraction is still very useful for studying the structure and distribution of cold H I clouds in the Galaxy. Preliminary results indicate that, while faint HISA occurs wherever H I backgrounds are bright, strong HISA is concentrated in cloud complexes, many of which lie in longitude-velocity structures tracing spiral arms [3].

Both populations require explanation, since simple differential rotation predicts only one distance for each radial velocity in the outer Galaxy, and HISA needs a background. In this case, the weak, ubiquitous HISA probably arises from ambient temperature fluctuations in the ISM revealed by turbulent eddies in the H I velocity field. The strong HISA requires a more organized process:

its distribution is consistent with an origin in the Perseus arm's velocity reversal [10]. Rapid cooling downstream of the spiral shock may also be the *source* of the cold H I appearing as strong HISA, though this is difficult to prove directly. The longitude-velocity distribution of HISA in the VGPS is even more striking, as Figure 2 demonstrates. Many prominent HISA structures lie nearly parallel to curves of constant Galactocentric radius in a simple model, much as spiral features might appear. These HISA structures appear more concentrated and organized than either the H I emission or the CO emission in the same region.

Acknowledgments

T. Bania and R.-J. Dettmar raised useful points that have been incorporated in the main text due to a lack of space for a separate discussion section. Information on CGPS and VGPS HISA can be found at www.ras.ucalgary.ca/∼gibson/hisa. An overview of the IGPS is available at www.ras.ucalgary.ca/IGPS. Figures were generated using Karma visualization software. This work is supported by a grant from the Natural Sciences and Engineering Research Council of Canada.

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