From Interstellar Clouds to Star-Forming Galaxies: Universal Processes?
Proceedings IAU Symposium No. 315, 2015
P. Jablonka, F. Van der Tak, & P. André, eds.

DOI: 00.0000/X000000000000000X

A Global View of Molecule-Forming Clouds in the Galaxy

Steven J. Gibson[1], Ward S. Howard[1,2,3], Christian S. Jolly[1,4], Jonathan H. Newton[1,5], Aaron C. Bell[1,6], Mary E. Spraggs[1,4], J. Marcus Hughes[1,4], Aaron M. Tagliaboschi[1], Christopher M. Brunt[7], A. Russell Taylor[8,9], Jeroen M. Stil[9], & Thomas M. Dame[10]

[1]Western Kentucky U., [2]Union U., [3]U. North Carolina-Chapel Hill, [4]C. M. Gatton Acad., [5]McMaster U., [6]U. Tokyo, [7]Exeter U., [8]U. Calgary, [9]U. Cape Town, [10]Harvard-CfA

Abstract. We have mapped cold atomic gas in 21cm line H I self-absorption (HISA) at arcminute resolution over more than 90% of the Milky Way's disk. To probe the formation of H_2 clouds, we have compared our HISA distribution with CO $J = 1 - 0$ line emission. Few HISA features in the outer Galaxy have CO at the same position and velocity, while most inner-Galaxy HISA has overlapping CO. But many apparent inner-Galaxy HISA-CO associations can be explained as chance superpositions, so most inner-Galaxy HISA may also be CO-free. Since standard equilibrium cloud models cannot explain the very cold H I in many HISA features without molecules being present, these clouds may instead have significant CO-dark H_2.

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

1. Overview

The gas in galactic disks occurs in a wide range of temperatures and densities, most of which are unsuitable for star formation. Somehow, diffuse atomic clouds are collected into colder, denser molecular clouds that can collapse under their own gravity. Molecular condensation is not directly observable, but it most likely arises in cold, quiescent pockets of atomic hydrogen (H I) gas, which over time will form molecular hydrogen (H_2) followed by more observable molecular species. Using algorithms developed previously (Gibson *et al.* 2005a,b), we have mapped the cold H I population traced by H I self-absorption (HISA; Gibson *et al.* 2000) against warmer H I emission in three large H I synthesis surveys (Gibson 2010; see Table 1). We then measured the mean fraction of positions

Table 1. High-Resolution H I and CO Surveys Used in This Study

Survey	Line	Telescope(s)	$\Delta\theta$	Δv	Plane Coverage, Area
CGPS[1]	H I 21cm	DRAO-ST + 26 m	1′	0.8 km/s	$52° < \ell < 193°$, 1240 deg^2
VGPS[2]	H I 21cm	VLA-D + GBT 100 m	1′	0.8 km/s	$18° < \ell < 67°$, 177 deg^2
SGPS[3]	H I 21cm	ATCA + Parkes 64 m	2′	0.8 km/s	$253° < \ell < 20°$, 274 deg^2
OGS[4]	^{12}CO 1-0	FCRAO 14 m	1′	0.8 km/s	$103° < \ell < 142°$, 328 deg^2
GRS[5]	^{13}CO 1-0	FCRAO 14 m	1′	0.2 km/s	$14° < \ell < 56°$, 83 deg^2
EOGS[6]	$^{12+13}$CO	FCRAO 14 m	1′	0.2 km/s	$56° < \ell < 192°$, 820 deg^2
UMSB[7]	^{12}CO 1-0	FCRAO 14 m	6′	1.0 km/s	$8° < \ell < 90°$, 164 deg^2
CfA[8]	^{12}CO 1-0	CfA 1.2 m, N + S	9′	0.6 km/s	$0° < \ell < 360°$, 11,000 deg^2

[1]Taylor et al. (2003); [2]Stil et al. (2006); [3]McClure-Griffiths et al. (2005); [4]Heyer et al. (1998); [5]Jackson et al. (2006); [6]Brunt *et al.* (in prep); [7]Sanders et al. (1986); [8]Dame et al. (2001);

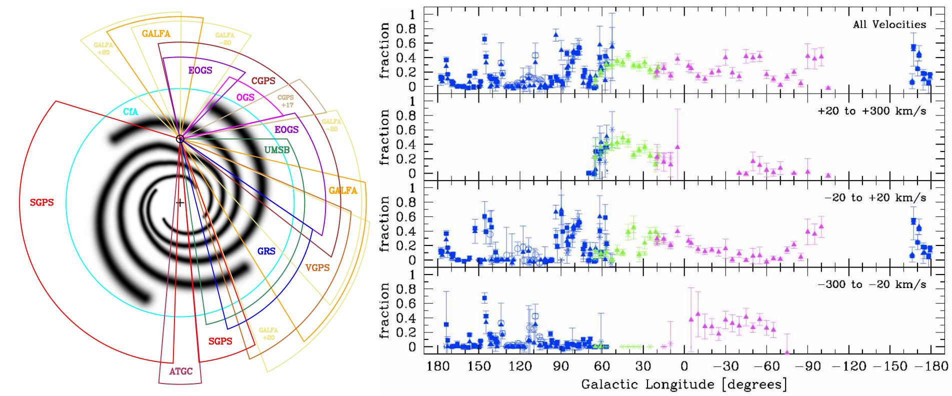

Figure 1. *Left:* Galactic disk coverage of H I and CO surveys used in this study (see Table 1). ATGC and GALFA data are not yet included. The spiral arm model is adapted from Taylor & Cordes (1993). *Right:* Corrected fractions of HISA voxels (volume pixels) with ^{12}CO emission at the same (ℓ, b, v) position, measured for different survey data sets vs. longitude within different LSR velocity ranges to separate trends for local, inner-Galaxy, and outer-Galaxy gas. Points give the mean fraction and 1σ error in the mean. The plotted fraction values are computed as the observed fraction minus the fraction expected if HISA and CO are unrelated physically and only align by chance, where the latter fraction is the product of the fraction of all voxels containing HISA and the fraction of all voxels containing CO. Threshholds used for significant detections are $\Delta T_{b,\mathrm{HISA}} < -15$ K and $T_{b,12\mathrm{CO}} > 1$ K.

with HISA that also have CO emission in other surveys (Table 1; Figure 1) to evaluate the evolutionary state of the HISA clouds.

We find that most HISA outside the Sun's orbit lacks CO emission at the same position and velocity, while most inner-Galaxy HISA has overlapping CO, but the latter may be illusory. If the expected number of HISA-CO matches due to chance alignments is removed, then the inner-Galaxy HISA-CO correspondence drops below $\sim 50\%$. Since HISA temperatures are too cold to explain easily with purely atomic gas (Wolfire *et al.* 2003), many HISA features may trace cold H I inside H_2 clouds that lack adequate UV shielding for abundant CO (e.g., Wolfire *et al.* 2010).

We also find that CO positions with HISA are even less common than HISA positions with CO, with a low enough fraction ($< 10\%$) to raise concerns about the use of HISA to resolve near/far kinematic distance ambiguities in inner-Galaxy sight lines.

Future steps in the analysis include corrections for FCRAO CO "error beam" sidelobe contamination, incorporation of other surveys, including GALFA-H I data from Arecibo, and comparison to synthetic observations of Galactic disk models.

Acknowledgements: Support for this work was provided by the U.S. National Science Foundation, NASA, Western Kentucky University, and the Gatton Academy.

References

Dame, T. M. *et al.* 2001, *ApJ*, 547, 792
Gibson, S. J. 2010, *ASP-CS*, 438, 111
Gibson, S. J., *et al.* 2005b, *ApJ*, 626, 214
Gibson, S. J., *et al.* 2005a, *ApJ*, 626, 195
Gibson, S. J., *et al.* 2000, *ApJ*, 540, 851
Heyer, M. H., *et al.* 1998, *ApJS*, 115, 241
Jackson, J. M., *et al.* 2006, *ApJS*, 163, 145
McClure-Griffiths, N. M., *et al.* 2005, *ApJS*, 158, 178
Sanders, D. B., *et al.* 1986, *ApJS*, 60, 1
Stil, J. M., *et al.* 2006, *AJ*, 132, 1158
Taylor, A. R., *et al.* 2003, *AJ*, 125, 3145
Taylor, J. H., & Cordes, J. M. 1993, *ApJ*, 411, 674
Wolfire, M. G., *et al.* 2010, *ApJ*, 716, 1191
Wolfire, M. G., *et al.* 2003, *ApJ*, 587, 278