Candidate Sites For Cold H_2 Formation in Cold HI Emission and Other Tracers

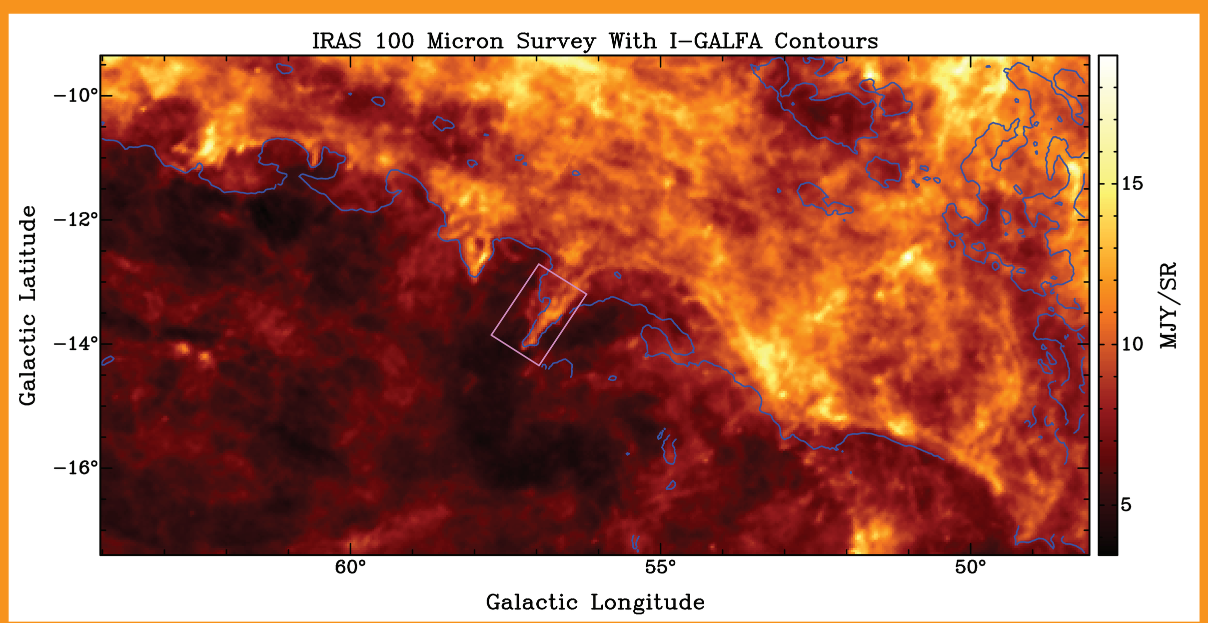
J. H. Newton, S. J. Gibson, K. A. Douglas, B. Koo, J. Kang, G. Park, J. E. G. Peek, E. J. Korpela, C. Heiles & T. M. Dame

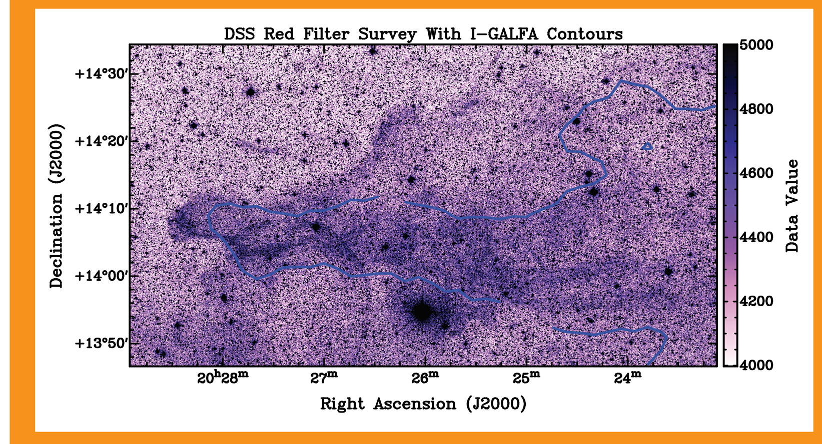
A New Cloud Is Seen

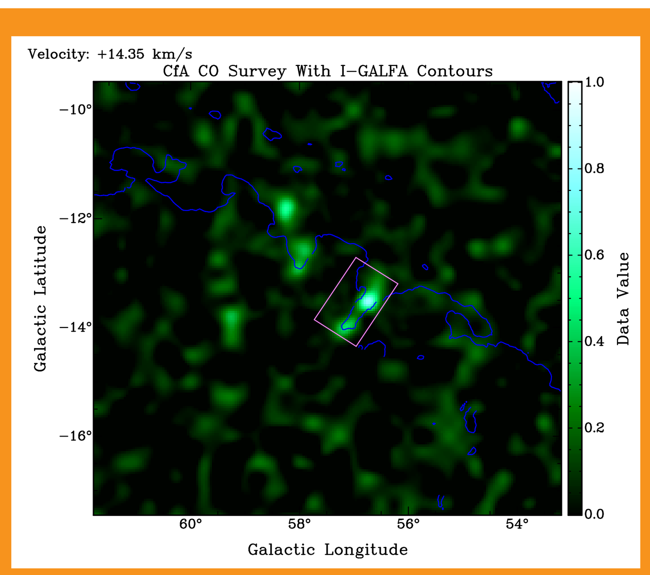
The I-GALFA HI survey has unveiled a unique HI front-like structure with a strong correlation to dust emissions. Dust in the cloud is readily visible at optical and infrared wavelengths. Denser areas also have counterparts in carbon monoxide (CO) emission. CO is a tracer of molecular hydrogen (H_2) indicating this is a newly discovered region is a molecular cloud. Whether this cloud will become colder and more dense leading to star formation depends on the amount of atomic, molecular and unobservable (dark) hydrogen. The amounts of these components can be estimated from the intensities of dust and CO emission. A byproduct of the analysis will be a set of parameter maps that will better help to understand why this region has such a unique shape.

Indirect Observations of Molecular Hydrogen

Molecular hydrogen can be observed directly via absorption lines in the ultraviolet spectrum under specific conditions described by Snow & McCall (2006). Unfortunately, no UV-bright stars are available in the region of interest. The symmetry of the H_2 molecule will prevent low-energy rotational transitions, so cold H_2 cannot be mapped or measured in emission. Without emission or absorption lines, we can use proxy tracers such as CO and dust to infer the presence of H_2 and estimate the amount of molecular hydrogen present using a relationship between the intensity of the given tracer and a conversion term known as the x-factor.







These images show multiwavelength emission associated with the HI feature. Above is 100μm data from the IRAS survey. The brighter the area the more dust present. The middle image is from the DSS survey in the red filter. The darker feature in the middle represents the section of the original HI cloud that has been analyzed. The bottom image is CO data taken from the CfA. The brighter green regions correspond to CO emission. The blue contour line outlines the HI emission. The purple box represents the optical field of view.

Determining the Amount of Atomic, Molecular and Dark Hydrogen Present and the Initial Results

The amount of unobservable H_2 hydrogen can be estimated from other measured or inferred HI and H_2 column densities. The total amount of hydrogen present is a product of the dust intensity an x-factor of 1.0×10^{20} cm²/(MJy/sr) from Reach et al. (1994). This relationship is given in equation 1.

$$N_{H_{total}} = X_{Dust} I_{Dust} \quad (1)$$

The amount of atomic hydrogen is calculated by isolating a single spectral feature. This is done by subtracting the target spectrum from one that is located off of the feature. The resulting values are analyzed by an HI line-fitting program, and the column density is found using equation 2.

$$N_{HI} = \frac{(T_s)\,(FWHM)\,(\tau_0)}{1.59\mathrm{x}10^{-19}\left[cm^2 \cdot K \cdot \frac{km}{s}\right]} \quad (2)$$

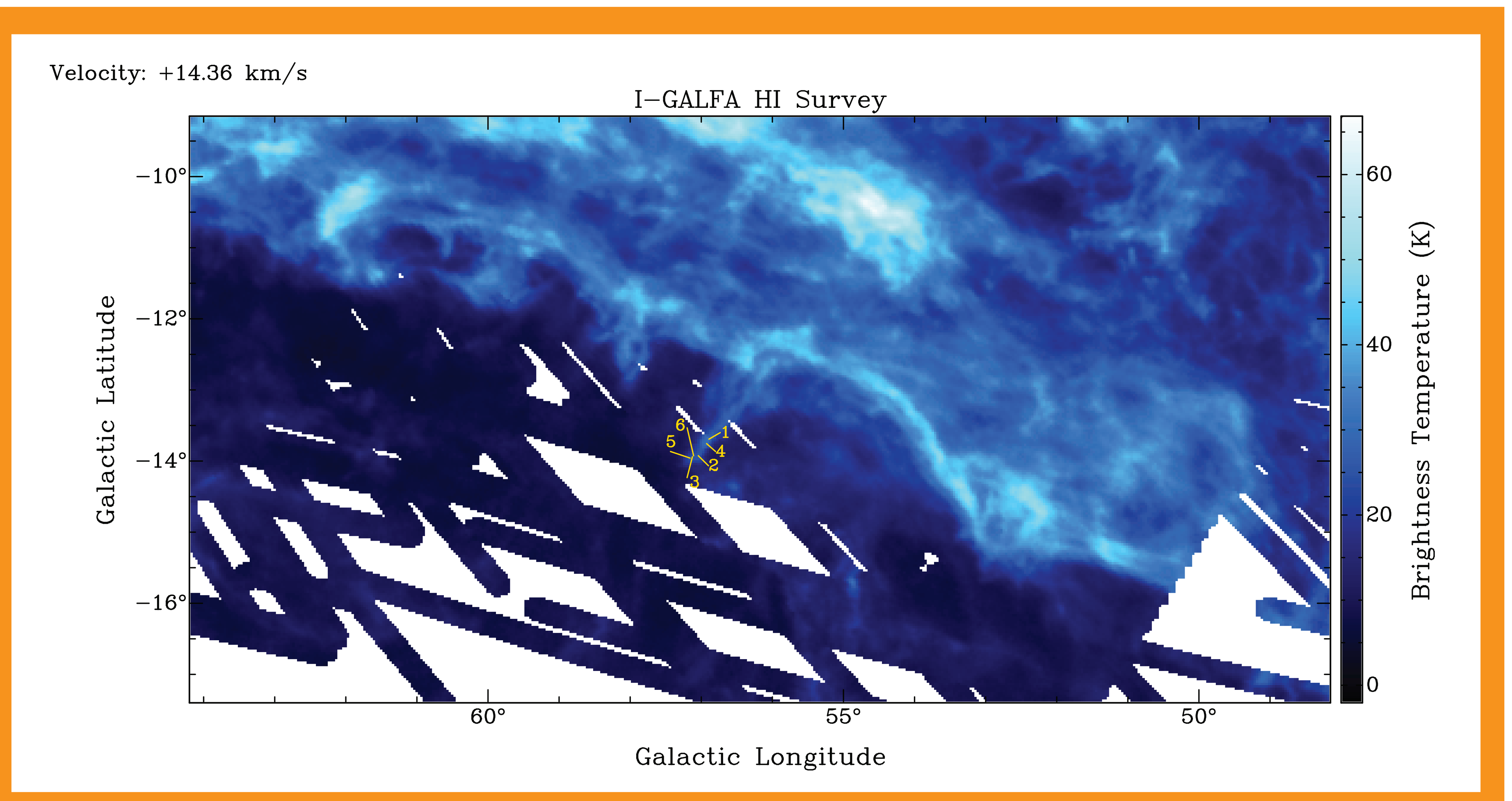
The column density of molecular hydrogen is established by the profile intensity of the carbon monoxide and the appropriate x-factor for CO and H_2 (equation 3).

$$N_{H_2} = X_{CO} W_{CO} \quad (3)$$

The difference between the total amount of hydrogen and the sum of atomic and molecular hydrogen yields the amount of dark hydrogen, displayed in equation 4.

$$N_{Dark} = N_{H_{Total}} - (N_{HI} + 2N_{H_2}) \quad (4)$$

Using equations 1-4 in a single spectrum analysis provides a way to constrain the composition of the feature. Initial testing of six spectra yielded several regions with negative amounts of dark hydrogen. The cause of this error was found to be that the x-factor used of $1.8\mathrm{x}10^{20}$ cm²/(K·km/s) from Dame et al. (2001) for the CO to H_2 was too large. Keeping $N_{Dark} \geq 0$ in equation 4 requires the x-factor for CO to H_2 to be around $2.37\mathrm{x}10^{19}$ cm²/(K·km/s).



The recently discovered HI region in the I-GALFA survey is pictured above. The feature lies on the bottom of the galactic plane and extends over a relatively large section of the sky. There are several key regions in this cloud, but the six innitial regions analyzed are marked one through six. We have begun our analysis with spectra at the positions indicated.

Current Status and Future Plans

We are modifying our software to analyze the region. This will allow us to find the maximum X_{CO} factor and to generate column density maps of the various gas components, which can be compared to each other to provide insight on the cloud's evolution and its unique shape. In order for the program to produce such maps over the entire regions, we are developing a robust method for detecting a single spectral feature and selecting appropriate OFF spectra.

Acknowledgements

This work would not have been possible without the use of the Arecibo Observatory and the people who aided in observations for the I-GALFA survey. The CO data would not have been possible without the help of the ongoing extensions to the CfA Composite Survey of Dame et al. (2001). IR data are from the Improved Reprocessing of IRAS Survey database (Miville-Deschenes & Lagache 2005). Funding for this project was provided by the NSF, Arecibo Observatory, NASA/JPL, and the NASA Kenctucky Space Grant Consortium.

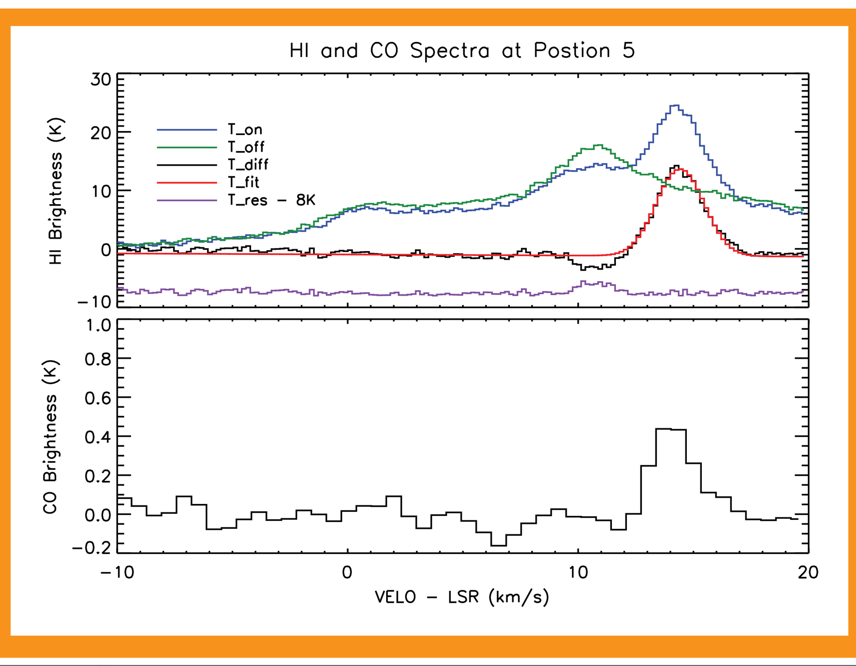
References

Dame, T. M., Hartmann, Dap, Thaddeus, P. (2001) The Milky Way in Molecular Clouds. The Astrophysical Journal, 547, 792-813.

Miville-Deschênes, Marc-Antoine, Lagache, Guilaine. (2005) IRIS: A New Generation of IRAS Maps The Astrophysical Journal Supplement Series, 157, 302-323.

Reach, William T., Koo, Bon-Chul, Heiles, Carl. (1994) Atomic and Molecular Gas in Sirrius Clouds, 429, 672-693.

Snow, Theodore P., McCall, Benjamin J. (2006) Diffuse Atomic and Molecular Clouds. The Annual Review of Astrophysics, 44, 367-414.



Spectrum Analyzed	N_{HI} Naive	N_{HI} Real	N_{H_2}	$N_{H_{Tot}}$	$N_{H_{Dark}}$
1	$1.34\mathrm{x}10^{20}$	$1.19\mathrm{x}10^{20}$	$2.21\mathrm{x}10^{20}$	$5.61\mathrm{x}10^{20}$	—
2	$9.49\mathrm{x}10^{19}$	$9.86\mathrm{x}10^{19}$	$2.31\mathrm{x}10^{20}$	$1.06\mathrm{x}10^{21}$	$4.96\mathrm{x}10^{20}$
3	$9.05\mathrm{x}10^{19}$	$6.84\mathrm{x}10^{19}$	$2.40\mathrm{x}10^{20}$	$9.12\mathrm{x}10^{20}$	$3.64\mathrm{x}10^{20}$
4	$1.41\mathrm{x}10^{20}$	$1.07\mathrm{x}10^{20}$	$1.89\mathrm{x}10^{20}$	$6.11\mathrm{x}10^{20}$	$1.27\mathrm{x}10^{20}$
5	$8.47\mathrm{x}10^{19}$	$6.48\mathrm{x}10^{19}$	$2.26\mathrm{x}10^{20}$	$8.14\mathrm{x}10^{20}$	$2.96\mathrm{x}10^{20}$
6	$9.70\mathrm{x}10^{19}$	$7.43\mathrm{x}10^{19}$	$2.25\mathrm{x}10^{20}$	$9.12\mathrm{x}10^{20}$	$3.88\mathrm{x}10^{20}$

Top: The top plots display several spectra that are used to determine the wellness of the selected off spectrum and the emission fit itself. The quality of the HI spectral fit is reflected in the flatness of T_{Diff} away from the main feature and in the fit residuals. The lower plot verifies that the HI and CO lines peak at about the same velocity.

Bottom: The table shows the gas component column densities for all six sightline. HI colums are given for optically thin gas (naive) and the fitted HI line shape (real; determined by equation 2). The H_2 column uses the maximum X_{CO} that does not give negative dark gas. The total column density is proportional to the dust intensity. The amount of dark hydrogen is the minimal amount of H_2 not accounted for by CO emission.

Contact Information:
Email: johnny.newtron@gmail.com
Phone: (859)327-6314