A Search for Hidden Molecular Clouds in the Milky Way

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Figure 1. The Milky Way galaxy is not an "empty" place. The Interstellar Medium(ISM) fills the galaxy with hydrogen and dust particles. NGC 6744 is very much like the our own galaxy. *Credit: European Southern Observatory*

Introduction

As galaxies are major components of the universe's structure, it is critical to understand their internal processes, such as star formation which occurs in the coldest, densest interstellar clouds. Unlike stars, these clouds are difficult to detect in visible light, but radio and infrared telescopes allow observations of the gas and dust particles they contain. In regions of the galaxy, ambient neutral atomic hydrogen gas is forming molecules, a sign of condensing clouds. We are interested in these clouds as precursors to stellar evolution where molecular hydrogen is critical. However, it is difficult to directly observe molecular hydrogen. Thus, proxy detectors such as carbon monoxide(12CO) are used as indicators of molecular hydrogen. This method isn't flawless. Through a comparative study, we propose that there is substantial dark molecular hydrogen not being seen with the current methods.

Figure 2. The 305meter Arecibo radio telescope in Puerto Rico serves as an excellent tool for investigating interstellar clouds. By observing the Hydrogen 21-cm line, key features of interstellar clouds can be determined. *Credit: National Astronomy and Ionosphere Center*

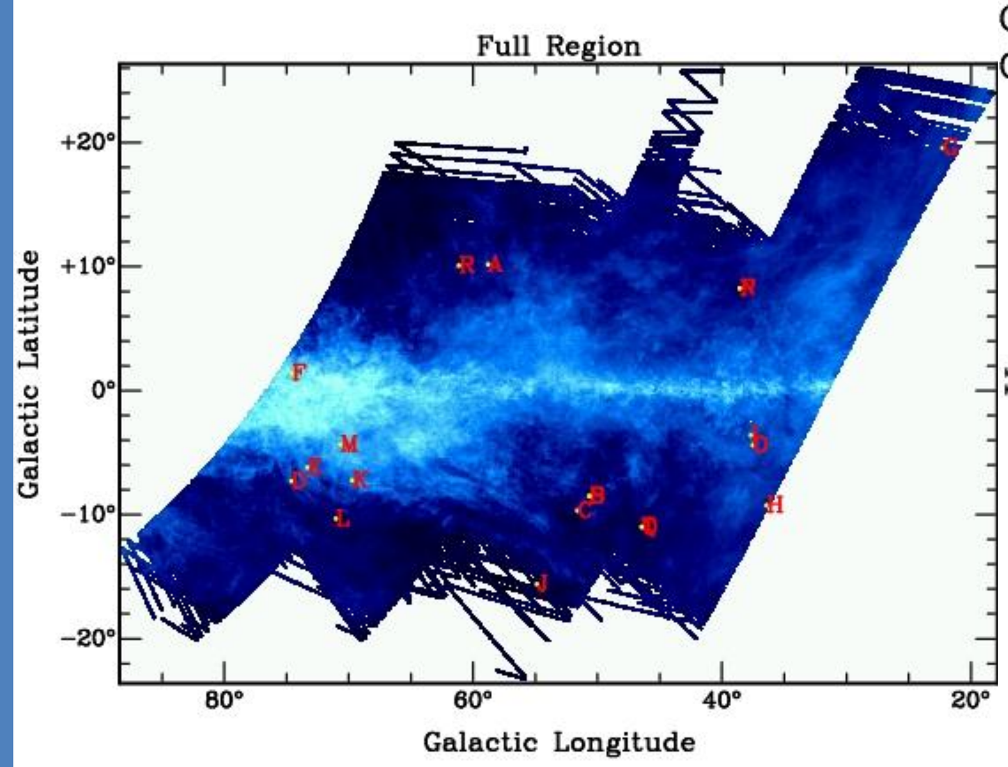

Figure 3. Above is a map of all the sample sites we have processed. Their position name is superimposed upon an I-GALFA full-survey image.

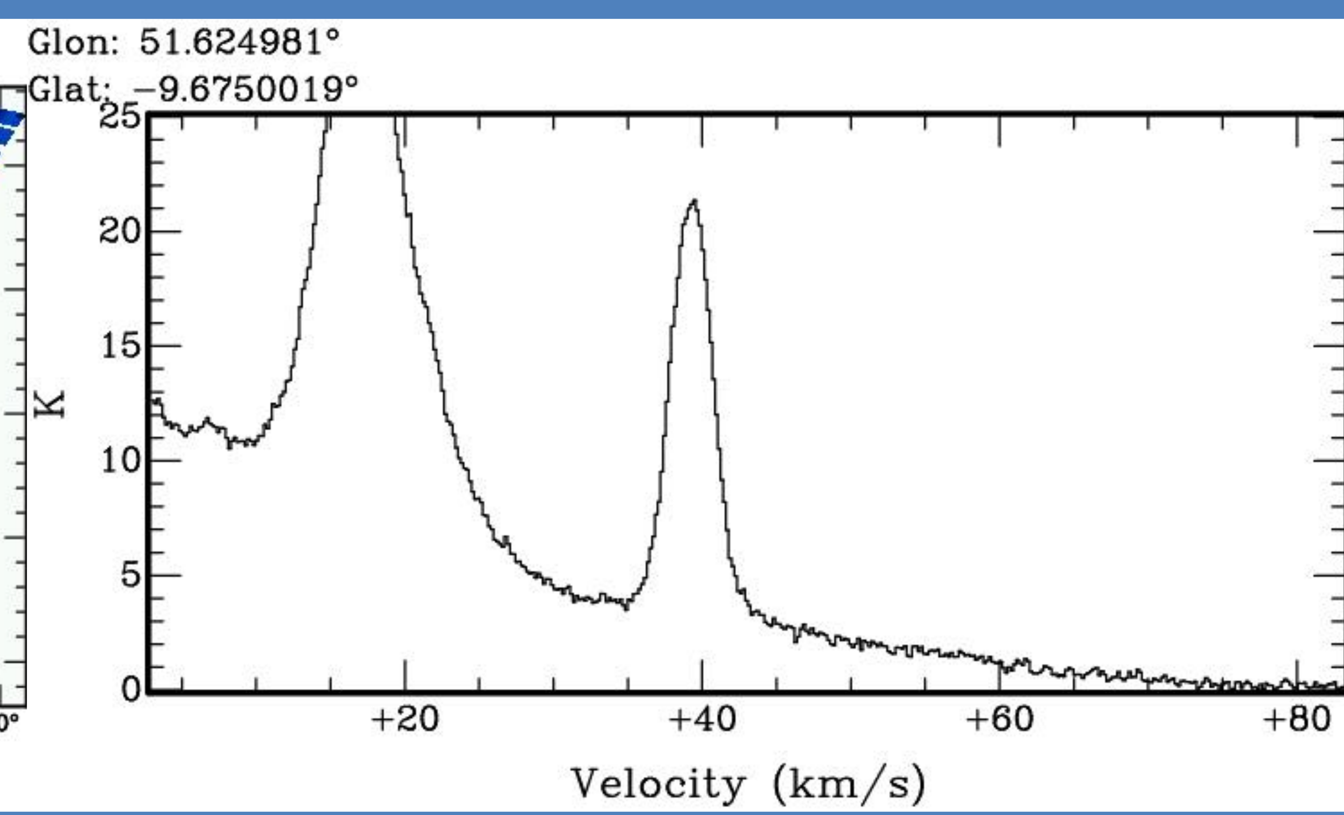

Figure 4. It is helpful to analyze the spectrum of a feature. At every position spatially in the I-Galfa data, there exists a spectrum. The above spectrum is from the maximum brightness location on Feature C(maps in Figure 5). Note how narrow the feature is at +39 km/s. Its full-width-half-maximum 2.58 km/s.

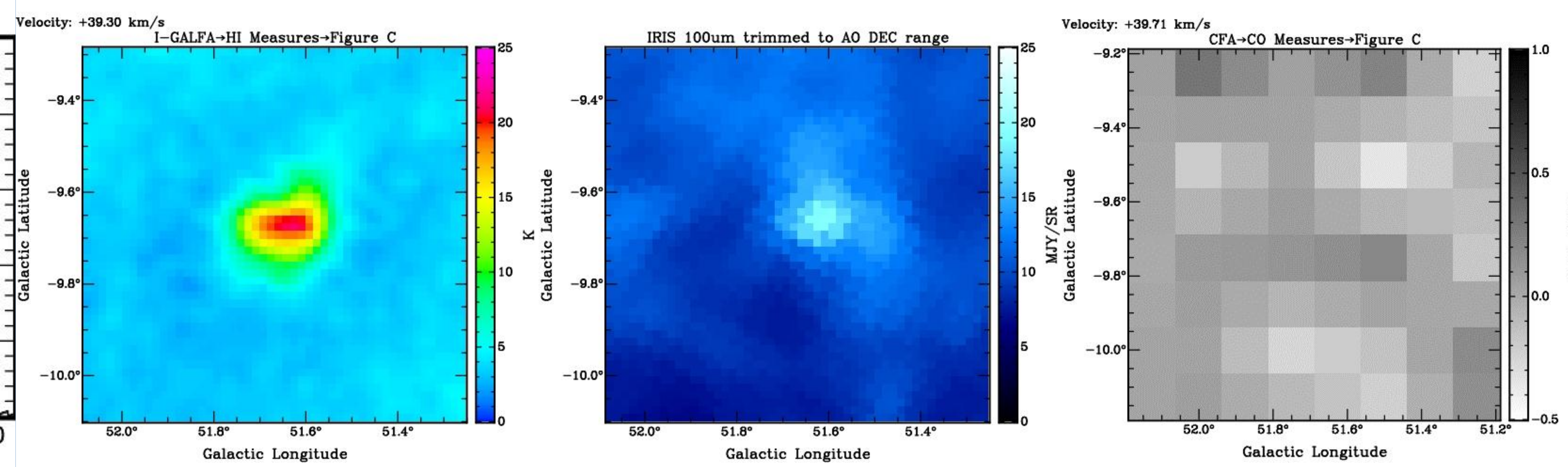

Figure 5. These images illustrate Feature C when observed under different spectral regimes. At left, is the HI I-GAFLA information used for initial analysis of the atomic hydrogen. The middle image is the same region in IRIS data at a wavelength of 100 microns, which has a brightness proportional to the total amount of gas and dust present. At right, available low-resolution CO data shows no matching detection.

Methods

Initially, we identified several cold, narrow-line (a few km/s) hydrogen clouds with I-GALFA HI data in the 21cm emission. After identification, we analyzed line properties of the feature manually considering the full-width-half-maximum, center line velocity, on brightness temperature, off brightness temperature, column density, apparent size, and several other properties. These were then analyzed by a line-fitting software designed by Jonathan Newton, to model the line features. As a comparison, we utilized IRAS IRIS infrared observations to extract total cloud and dust information performing similar measurements upon this data set at positions analogous to the HI analysis. To conclude, we compared the molecular column density as indicated by the carbon monoxide analysis.

Early Results

By comparing column densities of the 21-cm atomic gas emission and the infrared dust emission, an approximation of the total molecular hydrogen column density can be computed. There is insufficient visible molecular hydrogen from the CO proxy to account for the expected total indicating a dark molecular component. This is derived from:

$$N_{H_2(dark)} = \frac{N_{H(dust)} - N_{H(fit)}}{2} - N_{H_2(visible)}$$

Feature	N_H(simple)	N_H(fit)	N_H(dust)	N_{H2}(visible)	N_{H2}(dark)	Optical Depth	Temperature	Brightness	Line-Width
	cm^{-2}	cm^{-2}	cm^{-2}	cm^{-2}	cm^{-2}	unitless	K	K	km/s
A	$1.91x10^{20}$	$2.38x10^{20}$	$3.67x10^{20}$	$3.47x10^{19}$	$2.98x10^{19}$	1.026530	37.9523	21.6057	3.6126
B	$2.13x10^{20}$	$1.92x10^{20}$	$3.49x10^{20}$	$2.54x10^{19}$	$5.30x10^{19}$	0.232971	37.9523	16.9684	3.2868
C	$9.50x10^{19}$	$1.20x10^{20}$	$8.35x10^{20}$	$3.31x10^{18}$	$3.54x10^{20}$	1.174660	23.7535	18.2000	2.5848
G	$5.21x10^{19}$	$4.93x10^{19}$	$1.77x10^{21}$	$8.98x10^{19}$	$7.72x10^{20}$	0.570133	23.6209	16.1990	2.1103
H	$4.29x10^{19}$	$3.71x10^{19}$	$1.40x10^{20}$	$3.01x10^{19}$	$2.14x10^{19}$	0.032974	237.9325	9.4132	2.8850
I	$6.73x10^{19}$	$7.43x10^{19}$	$1.35x10^{21}$	$1.39x10^{20}$	$4.97x10^{20}$	0.677926	31.3669	21.5345	2.1715

Figure 6. Above is sample data from some of the features illustrating their characteristics and the amount of dark molecular hydrogen

Future Work

We wish to modify the line-fitting model of Jonathan Newton by adjusting for biases so a more correct model of the clouds can be ascertained. This will yield more information about the relationship between optical depth, temperature, etc. and the environment in which the cloud persists. Altogether this results in a greater understanding of the environmental impacts of the ISM.

References

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Acknowledgements: I-GAFLA data http://www.naic.edu/~igalfa/, CO data from the Center for Astrophysics http://www.cfa.harvard.edu/mmw/, IRAS IRIS maps http://irsa.ipac.caltech.edu/data/IRIS/docs/miville-deschenes2005.pdf,