Constraining the Physical Properties of Interstellar Gas Clouds

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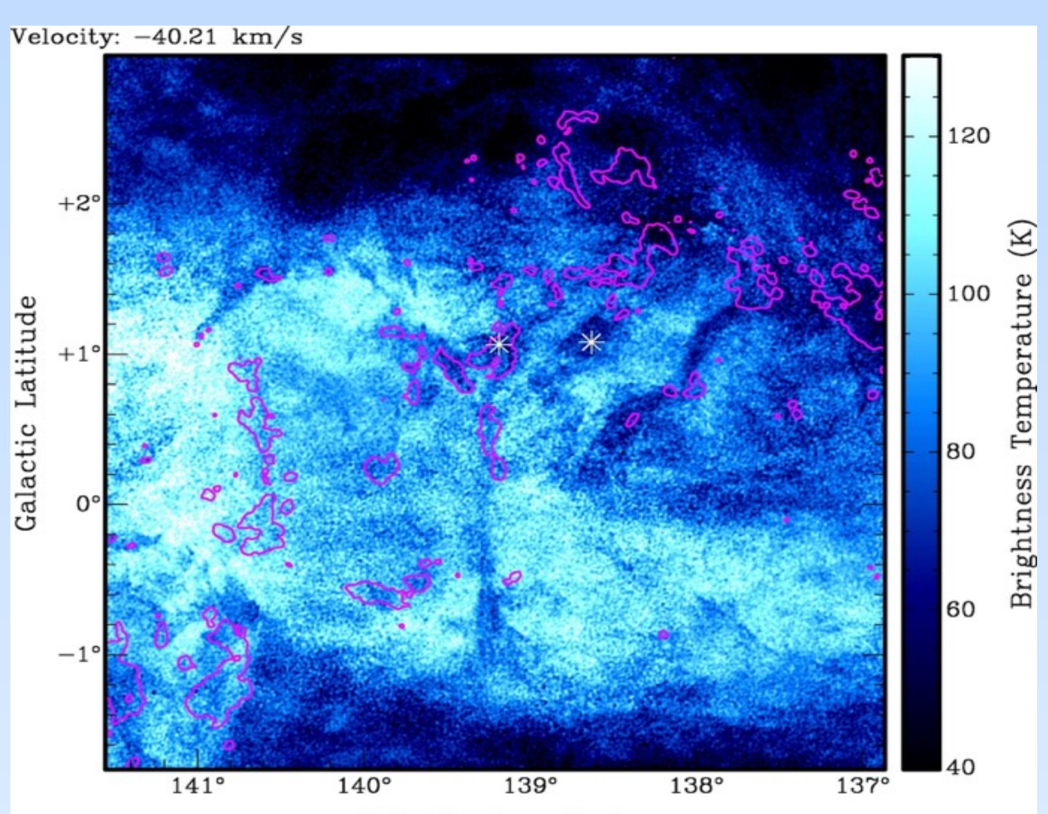
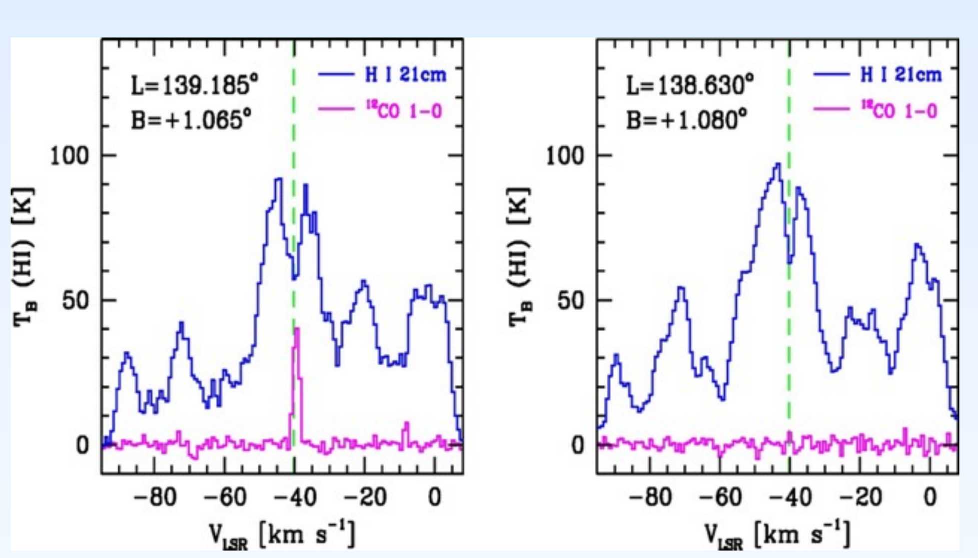
Background Information

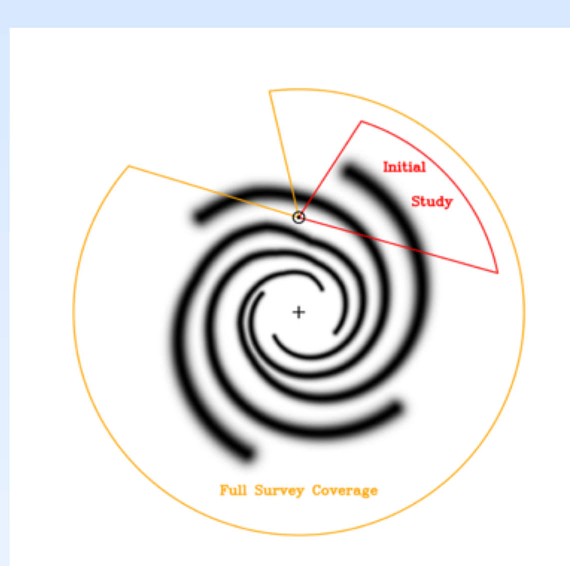
The interstellar medium (ISM) is the dynamic system of gas and dust that fills the space between the stars within galaxies. Due to its integral role in star formation and galactic structure, it is important to understand how the ISM itself evolves over time, including the process of cooling and condensing required to form new stars. This work aims to constrain and better understand the physical properties of the cold ISM with several different types of data, including large surveys of neutral atomic hydrogen (HI) 21cm spectral line emission and absorption, carbon monoxide (CO) 2.6mm line emission, and multi-band infrared dust thermal continuum emission. We are developing an algorithm that identifies areas where the gas may be cooling and forming molecules using HI self-absorption, in which a cold foreground HI cloud absorbs radiation from warmer background HI emission, and analyzes the HI spectral line in parallel with the CO and infrared data. From these inputs, the algorithm can determine the gas temperature, density, molecular abundance, and other properties as functions of position.



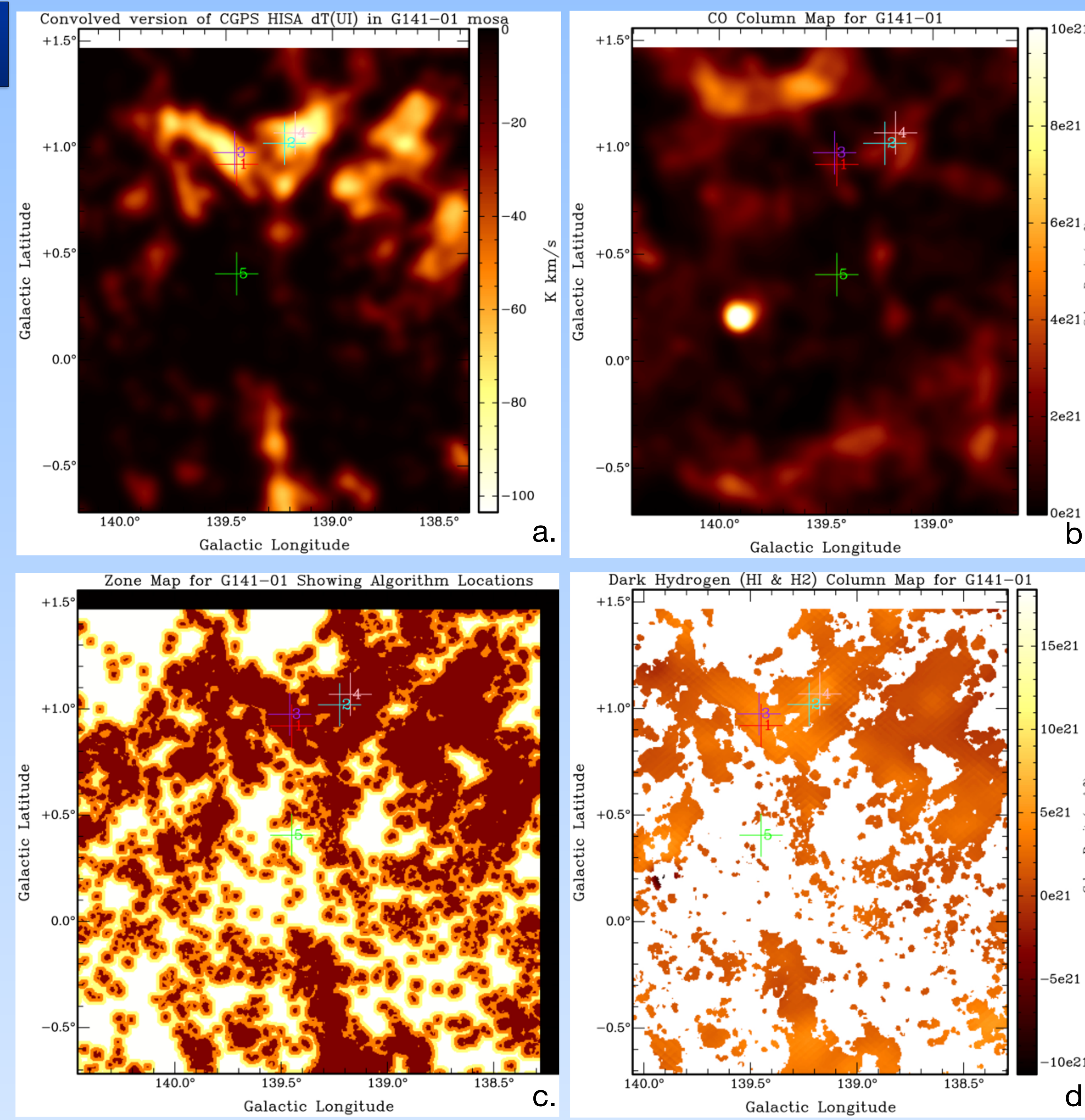
A channel map of HI 21cm line emission (CGPS; Taylor et al. 2003), showing cold atomic gas as dark blue HI self-absorption shadows (HISA; Gibson et al. 2000). Magenta contours show H_2 traced by CO (Heyer et al. 1998).



HI and CO spectra taken from positions marked with two white asterisks in the map above. The cloud on the left has a CO spike corresponding with a HISA dip, indicating cold atoms and molecules are both present. The cloud on the right has HISA without CO, so it may be in a less-developed state. There are many such clouds throughout the Galaxy (Gibson 2010).



A schematic plan view map showing the CGPS Phase 1 area (red) and the larger coverage of the International Galactic Plane Survey area (yellow) that we plan to analyze in the future.



Maps of the cloud under investigation: (a) convolved HISA integral map showing the ON-OFF brightness difference (from Gibson et al. 2005); (b) ^{12}CO *J*=1-0 emission tracing "visible" H_2 content (Heyer et al. 1998), smoothed to the *Planck* resolution, integrated over velocity, and scaled by 2 X_{CO} = 3.6 x 10^{20} cm^{-2} (K km/s)$^{-1}$ for H-atom column density (Dame et al. 2001); (c) a "zone" map showing areas ON and OFF the HISA cloud that can be used to constrain the amount of material in the cloud itself; (d) *Planck* dust column with HI and CO emission subtracted to show $N_{H, H2, dark}$, which is the column density of all hydrogen (atomic and molecular) not directly observed; Crosses in all panels mark target positions, for which results are tabulated. At the adopted distance of ~7500 light years, 0.1 degree = ~13 light years.

Results & Future Work

We have successfully demonstrated that a combined analysis of HI self-absorption plus CO and dust emission provides reasonable constraints on both the atomic/molecular content and gas properties of clouds where dark H_2 is actively forming. We are currently developing an automated method of applying this analysis to large areas of the Galaxy using HI, CO, and dust survey data sets. This will enable us to thoroughly investigate both the influence of internal properties on where H_2 forms within clouds and that of Galactic environment on where such clouds are most likely to arise, and what physical mechanisms (shocks, spiral density waves, etc.) may be responsible for their development.

Analysis

We have selected a prominent HISA cloud in the Perseus spiral arm for our initial investigation. HISA gas properties are not easy to constrain from the HI data alone, but by comparing the HISA to CO and dust, we are able to measure the fraction of atomic gas in the cloud. Using the *Planck* dust as a proxy for total gas content, we subtract the H_2 column traced by CO emission from this, leaving only a residual column of dark HI plus H_2 gas. If we assume the dark column outside the HISA boundaries is all molecular, this allows us to separate the dark HI plus H_2 column density components. The atomic gas fraction thus obtained is sufficiently precise to allow good constraints on other gas properties like temperature and density obtained via ideal gas relationships (Gibson et al. 2000).

Quantity	Range	Mean	Standard Deviation	Units
$N_{H, dust}$	29.3 – 71.2	49.3	11.9	10^{20} cm^{-2}
$N_{H, H2, CO}$	11.1 – 35.0	24.6	7.12	10^{20} cm^{-2}
$N_{H, H2, dark}$	0.0 – 14.8	0 - 5.07	0 - 7.5	10^{20} cm^{-2}
$N_{H, HISA}$	9.19 – 77.3	21.3 - 28.4	8.52 - 14.0	10^{20} cm^{-2}
$f_{n, HI}$	0.096 – 0.870	0.547 - 0.637	0.157 - 0.176	
$T_{S, HISA}$	7.33 – 21.83	11.13 - 11.78	3.78 - 3.86	K
$\tau_{0, HISA}$	0.228 – 0.466	0.345 - 0.350	0.082 - 0.084	
n_{total}	123.53 – 460.64	276.24 - 296.60	74.08 - 86.76	cm^{-3}

References

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