The Atomic-to-Molecular Hydrogen Transition in Giant Molecular Clouds

Elijah Bernstein-Cooper[1], Snežana Stanimirović[1], Min-Young Lee[2], Robert Lindner[1], Paul Goldsmith[3], Jouni Kainulainen[4]

[1]University of Wisconsin Madison, USA [2]Commissariat à l'Énergie Atomique et aux Énergies Alternatives, France [3]Jet Propulsion Laboratory, USA [4]Max-Planck Institute for Astronomy, Germany

Abstract

Lee et al. (2012) used H I and infrared data to estimate the H_2 distribution across the Perseus molecular cloud at sub-pc resolution, finding a saturation in the H I surface density, $\Sigma_{\rm HI}$, of 6–8 $M_\odot\,pc^{-2}$. The observed saturation agrees with the steady-state model of H_2 formation by Krumholz et al. (2009) which predicts that a saturation of $\Sigma_{\rm HI}$ is required to shield H_2 against photodissociation. As Perseus is a relatively low-mass and quiescent cloud however, we investigate California and Taurus which differ in both mass and star formation rates by a factor of 2–4 relative to Perseus (Lada et al., 2010). Our conclusions:

1. We use Planck A_V and GALFA-H I data to simultaneously estimate the dust-to-gas ratio (DGR) and the H I velocity width by modeling diffuse dust ($A_V < 1$ mag). With A_V, $N(\rm H\,I)$ and the DGR we estimate the H_2 surface density, $\Sigma_{\rm H2}$, and select core regions which trace the steepest A_V gradient. This method can be applied to other GMCs in a systematic way. We reproduce the results of Lee et al. (2012) with this method.
2. The model of Krumholz et al. (2009) fits the molecular fraction (H_2 / H I) as a function of the total gas density of regions in all three GMCs reasonably well. However, we find variations in the saturation $\Sigma_{\rm HI}$; Taurus shows a lower $\Sigma_{\rm HI}$ saturation. Further investigations of the CNM temperature using H I absorption spectra will offer insight to the lower $\Sigma_{\rm HI}$ saturation.

Data

- $\boldsymbol{N}$ **(H I)**: Galactic Arecibo L-band Feed Array (GALFA)-H I survey at 3.8′ resolution (Peek et al., 2011).
- $\boldsymbol{A_V}$: Planck survey color excess with a resolution of 5′ (Planck Collaboration et al., 2011). We assume $R_V = 3.1$ (Weingartner & Draine, 2001).
- $\boldsymbol{N}$ **(H_2)**: Assume that the dust column, traced by A_V, scales with the gas column such that $N(\rm H_2) = \frac{1}{2}\left(\frac{A_V}{\rm DGR} - N(\rm H\,I)\right)$. See Figure 1.
- ^{12}**CO**: Data from Dame et al. (2001) with a resolution of 8′.

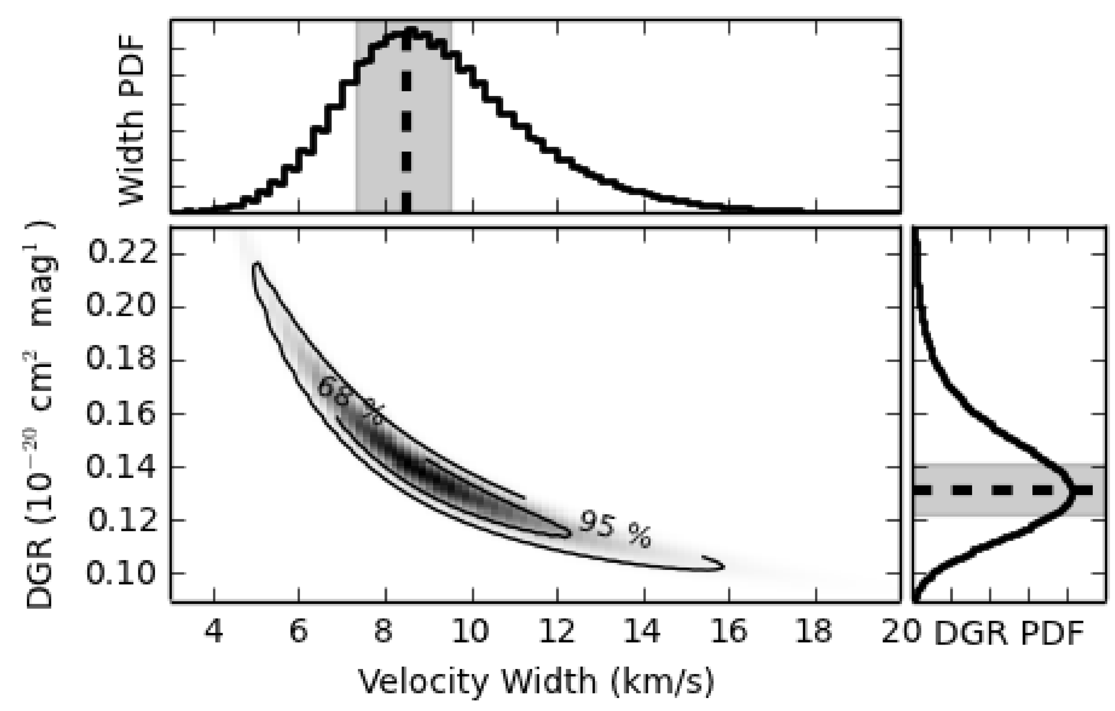

Figure 1: Plot of likelihood of DGR and H I integration velocity width for modeling the diffuse dust column, $A_V < 1$ mag, with H I in California. The 68% and 95% confidence intervals are shown as contours. The plots above and to the right represent the marginal probability density functions, where the dotted line is the mean, the maximum likelihood estimate, and the shaded region is the 68% confidence interval. We set the H I velocity center at the ^{12}CO peak.

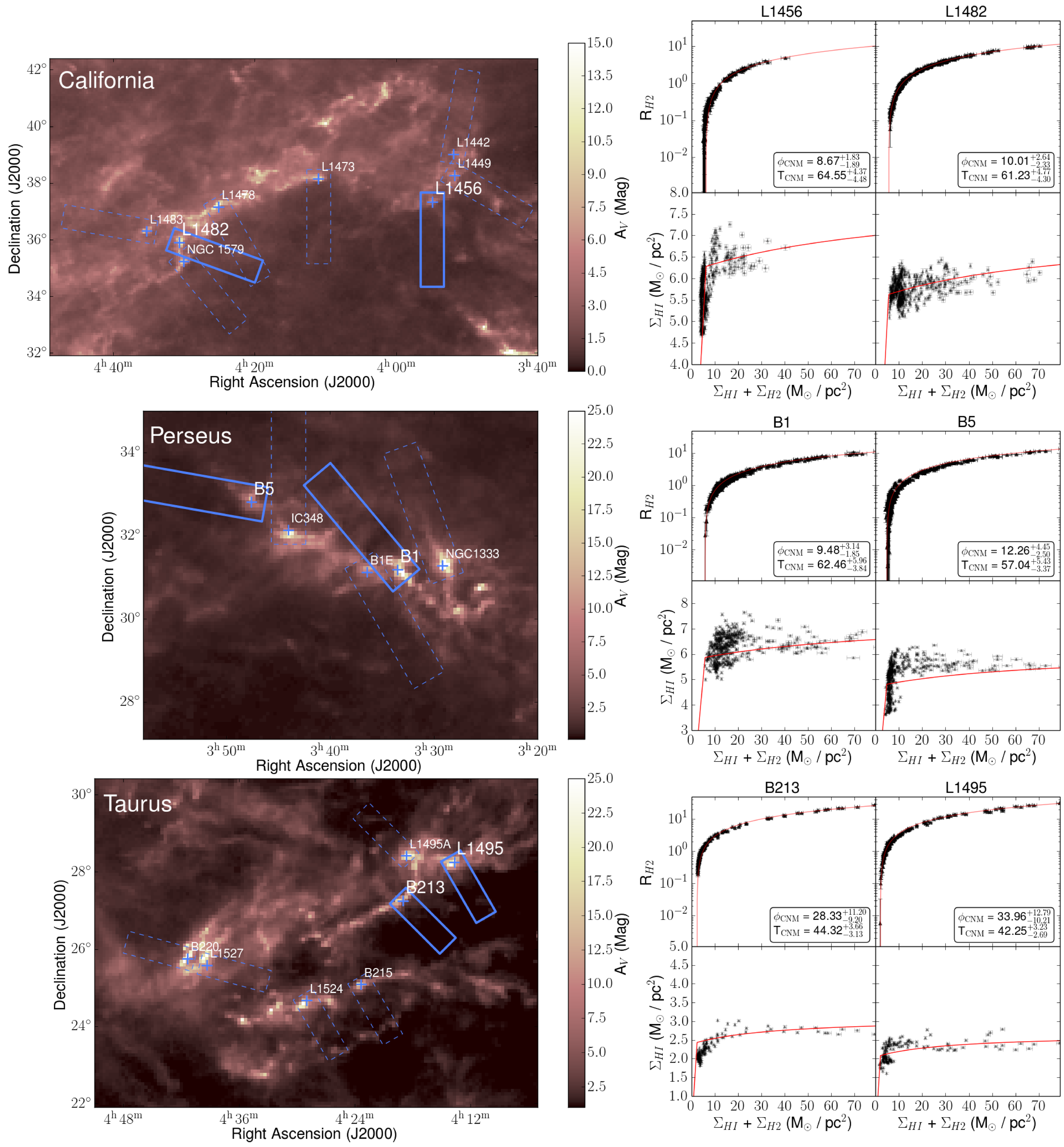

Figure 2: *Left column:* A_V maps of all three clouds from the Planck survey. The boxes outline the core regions which trace the steepest A_V gradients. *Right column:* The molecular fraction, $R_{H2} = \Sigma_{\rm H2} / \Sigma_{\rm HI}$, and H I surface density, $\Sigma_{\rm HI}$, as functions of the total gas surface density $\Sigma_{\rm H} = \Sigma_{\rm H2} + \Sigma_{\rm HI}$ for each molecular cloud. The steady-state model fit of Krumholz et al. (2009) is plotted in red. We fit for only the parameter $\phi_{\rm CNM}$ holding the metallicity $Z = 1\,Z_\odot$ and $\phi_{\rm mol} = 10$. We used the 2D distribution of likelihood estimates for $N(\rm H\,I)$ and the dust-to-gas ratio (see Figure 1 for an example) in a Monte Carlo simulation for error estimates in the Krumholz et al. (2009) model parameter $\phi_{\rm CNM}$.

Conclusion

The steady-state model of Krumholz et al. (2009) reasonably reproduces the observed molecular fraction in California, Perseus, and Taurus. California and Taurus have star-formation efficiencies 4× and 2× less than Perseus respectively, demonstrating the model can predict the molecular fraction across small variations in environment. California and Perseus show saturation H I surface densities of $\sim$6–8 $M_\odot\,pc^{-2}$ while Taurus shows saturations of $\sim$3 $M_\odot\,pc^{-2}$. See Figure 2. Lower CNM temperatures and higher CNM volume densities are required to explain the molecular fraction in Taurus.

References

Dame, T. M., Hartmann, D., & Thaddeus, P. 2001, ApJ, 547, 792
Krumholz, M. R., McKee, C. F., & Tumlinson, J. 2009, ApJ, 693, 216
Lada, C. J., Lombardi, M., & Alves, J. F. 2010, ApJ, 724, 687
Lee, M.-Y., Stanimirović, S., Douglas, K. A., et al. 2012, ApJ, 748, 75
Peek, J. E. G., Heiles, C., Douglas, K. A., et al. 2011, ApJS, 194, 20
Planck Collaboration, Abergel, A., Ade, P. A. R., et al. 2011, A&A, 536, A24
Weingartner, J. C., & Draine, B. T. 2001, ApJS, 134, 263

Contact Information

- Email: ezbc@astro.wisc.edu
- Website: http://www.astro.wisc.edu/~ezbc/

Visit https://bitbucket.org/ezbc/planckpy for transforming HEALPix Planck data to cartesian coordinates or scan the QR code.