H_2 Formation in the Perseus Molecular Cloud: Observations Meet Theory

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Abstract

To investigate the fundamental principles of H_2 formation in a GMC, we derive the HI and H_2 surface density (Σ_{HI} and Σ_{H2}) images of the Perseus molecular cloud on sub-pc scales (~0.4 pc). We use the IRIS 60 and 100 μm images and the 2MASS A_V image to derive the dust column density image of Perseus. In combination with the GALFA-HI data and an estimate of the dust-to-gas ratio (DGR), we then derive the Σ_{H2} distribution across Perseus. We find a uniform Σ_{HI} = 6–8 $M_\odot$ pc^{-2} for dark and star-forming regions, suggesting a minimum Σ_{HI} required to shield H_2 against photodissociation. As a result, a tight and consistent relation is found between the H_2-to-HI ratio and the total gas surface density. The transition between the HI- and H_2-dominated regions occurs at the total gas column density of (8–10) × 10^{20} cm^{-2}. Our findings are consistent with predictions for equilibrium H_2 formation and suggest that turbulence may not be of primary importance for H_2 formation.

Background

Krumholz, McKee, & Tumlinson (2009; KMT09) predict that R_{H2} in an atomic-molecular complex is primarily determined by its total gas column density, secondarily by its metallicity, and only weakly depends on the strength of interstellar radiation field. We test their predictions by investigating the H_2-to-HI ratio (R_{H2}) across the Perseus molecular cloud on sub-pc scales (~0.4 pc).

R_{H2} Image

(1) Σ_{HI}: We use the HI data from the GALFA-HI Survey (Peek et al. 2011). HI emission is integrated for –5~15 km s^{-1} based on the correlation between HI and dust column density.

(2) Σ_{H2}: First, we estimate the optical depth at 100 μm, τ_{100}, using the IRIS 60 and 100 μm images:

$$\tau_{100} = \frac{I_{100}}{B(T_{\rm dust}, \lambda_{100})}$$

where I_{100} is the intensity at 100 μm, $B(T_{\rm dust}, \lambda_{100})$ is the intensity of a blackbody of temperature $T_{\rm dust}$ at 100 μm. We derive $T_{\rm dust}$ from I_{60} / I_{100}. Second, we convert τ_{100} to A_V by finding X for $A_V = X\tau_{100}$ that minimizes the difference between our A_V and 2MASS A_V provided by the COMPLETE survey (Ridge et al. 2006). Finally, we calculate the H_2 column density, $N(H_2)$, from:

$$N({\rm H_2}) = \frac{1}{2}\left(\frac{A_V}{\rm DGR} - N({\rm HI})\right)$$

where we adopt DGR = 1.1 × 10^{-21} mag cm^2. The final R_{H2} image is presented in Figure 1.

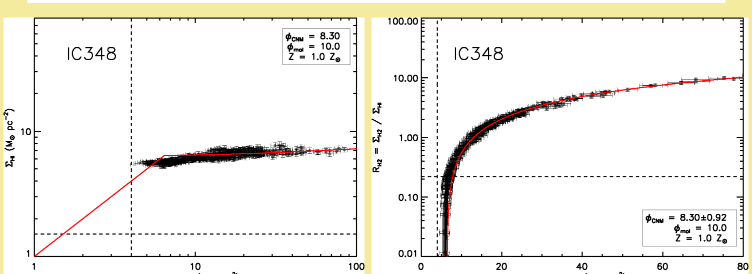

Figure 2. Σ_{HI} vs Σ_{HI}+Σ_{H2} (left) and R_{H2} vs Σ_{HI}+Σ_{H2} (right) for IC348. The best-fitting prediction from KMT09 is shown as a red solid curve.

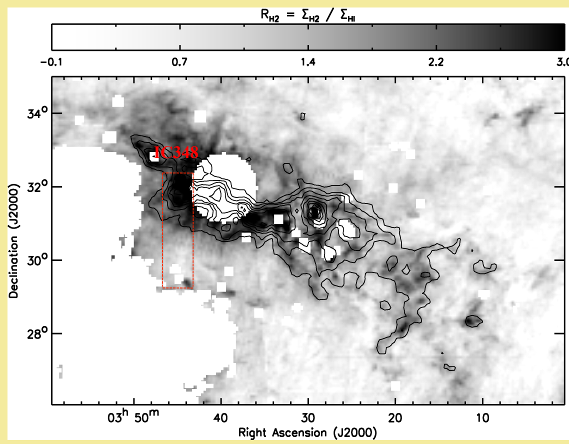

Figure 1. R_{H2} image of an angular resolution of 4.3' (~0.4 pc) (Lee et al. 2011). The region used for Figure 2 (IC348; star-forming region) is shown as a red box.

Results

In Figure 2, we plot Σ_{HI} (left) and R_{H2} (right) as a function of Σ_{HI}+Σ_{H2} for IC348. KMT09's prediction is shown as a red solid curve.

(1) Best-fitting paramete: We assume solar metallicity and find the best-fitting parameter $T_{\rm CNM}$ ~ 70 K. This CNM temperature is consistent with the CNM properties in the solar neighborhood (Heiles & Troland 2003).

(2) Constant Σ_{HI}: Σ_{HI} = 6–8 $M_\odot$ pc^{-2} is found for IC348. This is consistent with KMT09's prediciton for the minimum Σ_{HI} to form H_2, ~10 $M_\odot$ pc^{-2}.

(3) Transition column density: The transition from the HI- to H_2-dominated regions (R_{H2} ~ 0.25) occurs at N(HI)+2N(H_2) = (8–10) × 10^{20} cm^{-2}.

Conclusions

Based on the comparison between R_{H2} in Perseus and KMT09's prediction, we conclude that:

(1) Σ_{HI} = 6–8 $M_\odot$ pc^{-2} is required to form H_2 against photodissociaiton at solar metallicity and once it is acheived, Σ_{HI} stays constant and Σ_{H2} linearly increases.

(1) KMT09's model for equilibrium H_2 formation reasonably well describes R_{H2} as a function of total gas column density at sub-pc scales. This sugests that turbulence may not be of primary importance for H_2 formation.

References

(1) KMT09, ApJ, 693, 216

(2) Ridge et al. 2006, AJ, 131, 2921

(3) Heiles & Troland, 2003, ApJ, 586, 1067

(4) Lee et al. 2011, submitted

(5) Peek et al. 2011, ApJS, 194, 20