From atomic to molecular gas in the diffuse interstellar medium: the role of multi-phase neutral hydrogen

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Neutral hydrogen (HI) is the main ingredient for molecule formation and survival in the diffuse ISM. Yet, the role and importance of multiphase HI structure in the transition from atomic to molecular gas is still not understood. We have used observations of HI emission and absorption (Arecibo, VLA) and observations of HCO+, CCH, HCN, and HNC absorption (ALMA, NOEMA) to connect the early stages of molecule formation in the diffuse ISM with the underlying atomic gas properties. We find that these molecular species form along sightlines where $A_V > 0.25$, similar to the HI-to-H_2 transition at solar metallicity, and where the cold neutral medium column density is $>10^{20}$ cm^{-2}. The sightlines with the highest molecular column densities also have the most thermally unstable HI, suggesting that the unstable HI plays an important role in molecule formation and survival. We also detect a broad, faint component to the HCO+ absorption that spans most velocities where HI absorption is observed. This faint component is coincident in velocity with HI that has a lower cold neutral medium fraction than the HI at velocities where strong, narrow molecular absorption is observed. We also find thresholds for the optical depth, temperature, and turbulent Mach number of HI gas structures with a molecular component. By comparing to PDR chemical model predictions, we find that the kinetic temperature and the thermally unstable HI fraction separate our sample into two distinct categories. A lower HCO+ column density sample can be explained with modest density, FUV radiation field, and cosmic ray ionization rate (CRIR) models, while a higher HCO+ column density sample requires models with high density, FUV radiation field, and CRIR. The structures in the higher HCO+ column density sample have higher temperatures and are found in directions with more thermally unstable HI than the structures in the lower HCO+ column density sample.

References

[1] Murray, C. et al. 2018 ApJS, 238, 14
[2] Gong et al. 2017, ApJ, 843, 38
[3] Rybarczyk, D. et al. 2022a, arXiv:2109.06273
[4] Rybarczyk, D. et al. 2022b, arXiv:2112.05767