

# The $^{12}\text{C}/^{13}\text{C}$ Ratio in Diffuse Molecular Clouds

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The relative abundance of  $^{12}\text{C}$  to  $^{13}\text{C}$  incorporated into interstellar molecules is a probe of the chemical processes active in the interstellar medium (ISM). The  $^{12}\text{C}/^{13}\text{C}$  ratio in diffuse environments is expected to vary with molecular species according to chemical models that include the effects of photodissociation and charge exchange reactions. The model predictions can be tested through a detailed analysis of absorption lines of CN and  $\text{CH}^+$  in optical spectra and of CO in the ultraviolet. Here, we present high-resolution, high signal-to-noise observations of optical transitions in CN and  $\text{CH}^+$  for six diffuse clouds. The data are examined to extract the  $^{12}\text{CN}/^{13}\text{CN}$  and  $^{12}\text{CH}^+ / ^{13}\text{CH}^+$  ratios along each line of sight. The results, along with our recent measurements on  $^{12}\text{CO}/^{13}\text{CO}$  ratios from an archival study using *HST*,<sup>1</sup> are then used to assess predictions of diffuse cloud chemistry.

The best measure of the ambient carbon isotopic ratio in diffuse molecular clouds is believed to be the  $^{12}\text{CH}^+ / ^{13}\text{CH}^+$  ratio.  $\text{CH}^+$  is not subject to chemical fractionation because its formation, via the endothermic reaction,<sup>2</sup>  $\text{C}^+ + \text{H}_2 \rightarrow \text{CH}^+ + \text{H}$ , involves non-thermal processes such as magnetohydrodynamic shocks or propagating Alfvén waves. An examination of the four sight lines in our sample with detectable  $^{13}\text{CH}^+$  reveals  $^{12}\text{CH}^+ / ^{13}\text{CH}^+$  ratios near 70 for all directions, consistent with the average for local interstellar clouds. Other carbon-bearing molecules which are susceptible to fractionation, such as CO, may exhibit either enhanced or reduced 12-to-13 ratios as a result of two competing effects. Selective photodissociation favors  $^{12}\text{CO}$  since, being the more abundant isotopologue, it is protected to a greater extent via self shielding. Conversely, isotope charge exchange,  $^{13}\text{C}^+ + ^{12}\text{CO} \rightarrow ^{12}\text{C}^+ + ^{13}\text{CO} + 35 \text{ K}$ , favors  $^{13}\text{CO}$  which has a lower zero-point energy.<sup>3</sup> Because CO is the most abundant carbon-bearing molecule in the ISM, an enhancement in  $^{12}\text{CO}$  ( $^{13}\text{CO}$ ) will deplete the carbon reservoir of  $^{12}\text{C}$  ( $^{13}\text{C}$ ). Thus, any molecule arising from the remaining carbon in the reservoir will have a 12-to-13 ratio opposite that seen in CO. This behavior is expected for CN because the two molecules occupy the same portion of the cloud<sup>4</sup>. In our *HST* survey of interstellar CO, the two sight lines with the highest isotopologic ratios are  $\rho$  Oph A and  $\zeta$  Oph, with respective values of  $^{12}\text{CO}/^{13}\text{CO}$  equal to  $125 \pm 36$  and  $167 \pm 25$ . Our measured  $^{12}\text{CN}/^{13}\text{CN}$  ratios toward these stars are  $54 \pm 14$  for  $\rho$  Oph A and  $49 \pm 20$  for  $\zeta$  Oph. Together, these results provide evidence for the opposing effects of chemical fractionation in CO and CN at work in diffuse molecular environments.

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<sup>1</sup>Sheffer, Y., Rogers, M., Federman, S. R., Lambert, D. L., & Gredel, R. 2007, ApJ, 667, 1002

<sup>2</sup>Elitzur, M., & Watson, W. D. 1978, ApJ, 222, L141

<sup>3</sup>Watson, W. D., Anicich, V. G., & Huntress, W. T., Jr. 1976, ApJ, 205, L165

<sup>4</sup>Pan, K., Federman, S. R., Sheffer, Y., & Andersson, B.-G. 2005, ApJ, 633, 986