Complex Carbon Isotope Fractionation in a Protoplanetary Disk

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Chemical information is vital to understanding material evolution during planetary system formation. Specifically, isotopologue ratios are of interest because they could conserve the formation history of molecules, linking the planetary system bodies and their birth environment, protoplanetary disks. Hereafter, we focus on the carbon isotope ratio, $^{12}C/^{13}C$, in the gas phase of the nearest protoplanetary disk around TW Hya. Recent measurement suggests that significant carbon isotope fractionation occurred in this disk while the $^{12}C/^{13}C$ ratio in the local interstellar medium (ISM) is ~70. Zhang et al. (2017) and Yoshida et al. (2022) found significantly low $^{12}C^{18}O/^{13}C^{18}O$ and $^{12}CO/^{13}CO$ of 20-40. On the other hand, $H^{12}CN/H^{13}CN$ is estimated to be ~86 by Hily-Blant et al. (2019).

In this talk, we present the first spatially-resolved detection of ^{13}CN with the Atacama Large Millimeter/sub-millimeter Array. By combining archival ^{12}CN observations, we derived the $^{12}CN/^{13}CN$ ratio to be ~70 with non-local thermal equilibrium (non-LTE) modeling. Additionally, we found tentative evidence of a dip of $^{12}CN/^{13}CN$ at ~100 au, where the ratio decreases to ~50.

Different molecules exhibit different carbon isotopologue ratios in the TW Hya disk. In terms of the molecular column densities, the main carbon carrier in the gas phase is CO. Therefore, if the bulk carbon isotope ratio is the same as the ISM value, there are significant amount of hidden ^{12}C in the solid phase. This might be caused by an isotope exchange reaction between CO and carbon ions under the environment where the carbon-to-oxygen ratio (C/O) is larger than unity in the past. The higher isotopologue ratios found in other molecules would be explained by the isotope exchange reaction and/or vertical variation of the C/O ratio. Indeed, our non-LTE modeling implies that the CN line traces the disk atmosphere rather than near the midplane where CO isotopologue measurement traces. This study sheds light on complex carbon isotope fractionation patterns, requesting a more detailed understanding of the isotope chemistry.

References

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