A new method for direct measurement of isotopologue ratios in protoplanetary disks: heterogeneity of the $^{12}CO/^{13}CO$ ratio in the TW Hya disk

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Isotope ratios are a promising tool to investigate the material evolution from interstellar space to planetary systems. For example, the high deuterium-to-hydrogen ratio observed in molecular clouds and comets suggests that the material was formed in a low-temperature environment. The mass-independent oxygen isotope anomaly observed in the solar system is explained related to the fractionation by photochemistry in the universe. Therefore, it is important to measure isotope ratios in protoplanetary disks, the birthplace of planets, by astronomical observations. However, the measurement is challenging because emission lines of major isotopologues are optically thick and that of minor isotopologues are hard to detect.

To overcome the difficulties, we developed a new method to measure isotopologue ratios in protoplanetary disks. Since emission lines are broadened owing to the thermal motion, the line wings are optically thin even if the line center is optically thick. Therefore, we can measure the isotopologue ratios using the line wings. We used a detailed disk model and verified this idea.

Furthermore, we applied the method to measure the $^{12}CO/^{13}CO$ ratio in a protoplanetary disk around TW Hya using ALMA archival data. As a result, it was found that $^{12}CO/^{13}CO$ is ~0.4 times lower than an averaged value in the interstellar matter (ISM) at <100 au. This can be explained by an isotope-exchange reaction between carbon ions and CO molecules with C/O > 1. Beyond 100 au, the ratio is ~1.6 times higher than the ISM value, which suggests that a difference of the binding energy to ice between ^{12}CO and ^{13}CO and the CO gas depletion played a role. Our results imply that the ratio can vary by a factor of >4 even inside a protoplanetary disk, and therefore, can be used to trace material evolution in disks, although the $^{12}C/^{13}C$ ratio is thought to be almost constant in the solar system.

Keywords: Protoplanetary disk, Isotope ratio, Astrochemistry, Planet formation, ALMA

