A new measurement method of isotopologue ratios in protoplanetary disks: a case study of the ^{12}CO/^{13}CO ratio in the TW Hya disk

T. Yoshida,[1, 2] H. Nomura,[1, 2] K. Furuya,[2] T. Tsukagoshi[2] and S. Lee[2]

[1] *Department of Astronomical Science, The Graduate University for Advanced Studies, SOKENDAI, Japan*

[2] *National Astronomical Observatory of Japan*

Isotope ratio is a powerful tool to investigate the material origin and evolution from molecular clouds to planetary systems. For instance, the ratio of deuterium to hydrogen can be used as a tracer of material formed in a low-temperature environment, permitting us to study the origin of water on the Earth. The oxygen isotope ratios have an anomaly in the solar system, which is considered to reflect mass-independent fractionation of the carbon monoxide (CO) molecule in the pre/early stage of the solar system formation [1]. To explain the isotopic compositions in planetary systems, physicochemical models of molecular clouds and protoplanetary disks have been proposed.

Despite its importance, however, the observational constraint is difficult especially in protoplanetary disks. The molecular gas in protoplanetary disks is observed in emission lines. Since isotopologue ratios often reach tens and handreds, it is common that rarer isotopologue emission becomes too weak to be detected. In contrast, when the rarer isotopologue line is bright enough, the main isotopologue line (center) becomes optically thick, which makes column density measurement impossible. However, the lines broaden due to thermal motion in general, which makes line wings optically thin. Therefore, we have a chance to measure the isotopologue ratios by observing the multiple isotopologue line wings.

We present that the isotopologue ratios in protoplanetary disks can be practically measured using the line wings, assuming high velocity resolution observations with Atacama Large Millimeter/submillimeter Array (ALMA). Detailed disk models are used for proof of the method. Moreover, we analyzed archival ALMA observations of the ^{12}CO 3-2 and ^{13}CO 3-2 lines toward a protoplanetary disk around a T Tauri star, TW Hya. The ^{12}CO/^{13}CO ratio in the outer disk (R~60-100 au) was estimated to be 23±6, which is extremely smaller than the canonical interstellar value of 69±6 [2]. This could imply that a volatile C/O ratio larger than unity promotes an isotope exchange reaction between the carbon ions and the CO molecules, making ^{13}CO richer. Indeed, such a high C/O ratio has been suggested in previous observations of hydrocarbon species [3]. In addition, it is also suggested that the ^{12}CO/^{13}CO ratio is enhanced beyond a radius of 120 au with a lower limit of ~100, although the origin is unclear.

References

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