Deuterated water in turbulent protoplanetary disks

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Deuterated water observed in the current solar nebula can provide insights into how water has evolved in the primitive solar nebula. So far, D/H ratios in cometary water have been measured in seven comets, six from the Oort Cloud (~(3–5)X10^{-4}; e.g., Mumma et al. 2011, and references therein), one from the Kuiper Belt (~1.6X10^{-4}; Hartogh et al. 2011). In all of them, deuterium concentrates by about an order of magnitude relative to the elemental abundance of deuterium in the interstellar medium (~1.5X10^{-4}; Linsky 2003). A key question is when this ratio is established during the star and planet formations. Here, we focus on the protoplanetary disk phase.

Deuterium fractionation in plotoplanetary disks have been studied numerically (e.g., Aikawa & Herbst 1999). Willacy et al. (2009) investigated deuterium chemistry in inner disks (< 30 AU) considering the radial accretion. They found that the D/H ratio in water ice in the midplane retains their initial ratio (~10^{-2}, which set by their dense cloud core model) for 10^6 yr, since water ice is not destroyed efficiently there. However, we note that turbulent mixing could change the situation drastically. Oxygen is mainly in atomic form in the disk atmosphere, while it is in water ice in the midplane (e.g., Bergin et al. 2007, and references therein). If the turbulence exists, water ice would be transported to the disk atmosphere and destroyed by photoreactions and/or thermal desorption, while atomic oxygen would be transported to the disk midplane and reform water ice. If such destruction and reformation processes occur effectively, the D/H ratio in water ice would be lowered or enhanced depending on the atomic D/H ratio near the disk midplane.

In this presentation, we report the effect of turbulent mixing in the vertical direction on the D/H ratio of water in protoplanetary disks. We solved the rate equations with diffusion terms, which mimic the turbulent mixing, adopting the physical model of a disk surrounding a typical T Tauri star (Nomura et al. 2005, 2007). A collapsing core model is calculated to set the initial molecular abundances of our disk models, in which the D/H ratio in water ice is ~10^{-2}. The D/H ratio in water ice in the midplane does not significantly change for 10^6 yr in the case of alpha=10^{-3}, while it decreases to ~10^{-3} at R=10–30 AU in the case of alpha=10^{-2}. The model ratio remains higher than the cometary ratio. It indicates that in the case of the solar nebula, the D/H ratio in water might be already much less than 10^{-2} in the early phase of the disk.

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