Possibility to locate the position of the H_2O snowline in protoplanetary disks using high-dispersion spectroscopic observations with ALMA

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Inside the H_2O snowline of protoplanetary disks, water evaporates from the dust-grain surface into the gas phase, whereas it is frozen out onto the dust in the cold region beyond the H_2O snowline. H_2O ice enhances the solid material in the cold outer part of a disk, which promotes the formation of gas-giant planet cores. We can regard the H_2O snowline as the surface that divides the regions between rocky and gaseous giant planet formation (e.g., Hayashi et al. 1981, 1985). Observationally measuring the location of the H_2O snowline is crucial for understanding the planetesimal and planet formation processes, and the origin of water on Earth.

We found candidate water lines to locate the position of the H_2O snowline through high-dispersion spectroscopic observations of the velocity profiles of the emission lines of H_2O in disks (Notsu et al. 2016 & 2017, ApJ). The velocity profiles are affected by Doppler shift due to Keplerian rotation. Therefore, the line profiles are sensitive to the radial distribution of the line emitting regions. First, we calculated the chemical composition of the disks around a T Tauri star and a Herbig Ae star using chemical kinetics. We confirmed that the abundance of H_2O gas is high not only in the hot midplane region inside the H_2O snowline but also in the hot surface layer and the photodesorbed region of the outer disk. Second, we calculated the water line profiles and identified that ortho-$H_2{}^{16}O$ lines with small Einstein A coefficients ($\sim 10^{-6}$–10^{-3} s^{-1}) and relatively high upper state energies (~1000K) are dominated by emission from the hot midplane region inside the H_2O snowline. Therefore, through analyzing their line profiles the position of the H_2O snowline can be located. The wavelengths of the candidate H_2O lines to locate the position of the H_2O snowline range from mid-infrared to sub-millimeter, including the ALMA bands. The total line fluxes tend to increase with decreasing wavelengths, and increasing central stellar mass.

Moreover, we investigated the properties of the sub-millimeter ortho/para-$H_2{}^{16}O$ and $H_2{}^{18}O$ lines, and found that because the number densities of the ortho- and para- $H_2{}^{18}O$ molecules are around 560 times smaller than their ^{16}O analogues, they can trace deeper into the disk (down to z~0), depending on the dust optical depth (Notsu et al. 2018, ApJ). The values of the Einstein A coefficients of sub-millimeter candidate water lines tend to be smaller (typically $<10^{-4}$ s^{-1}) than infrared candidate water lines. Thus, in the sub-millimeter candidate water line cases, the emissivity from the outer optically thin region in the disk is around 10^4 times smaller than that in the infrared candidate water line cases. Therefore, in the sub-millimeter water lines, especially ortho- and para-$H_2{}^{18}O$ lines with relatively smaller upper state energies (~ a few 100K) are suitable to locate the position of the H_2O snowline.

Finally, we have proposed the water line observations for a Herbig Ae disk (HD163296) in ALMA Cycle 3, and partial data were delivered. We would introduce the current analysis results, and discuss the possibility of future high-dispersion spectroscopic observations using ALMA (Bands 5-10).

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