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Possibility to locate the position of the H_2O snowline in protoplanetary disks through spectroscopic observations

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Abstract. Observationally locating the position of the H_2O snowline in protoplanetary disks is crucial for understanding planetesimal and planet formation processes, and the origin of water on the Earth. In our studies, we conducted calculations of chemical reactions and water line profiles in protoplanetary disks, and identified that ortho/para-$H_2{}^{16}O$, $H_2{}^{18}O$ lines with small Einstein A coefficients and relatively high upper state energies 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. Moreover, because the number density of the $H_2{}^{18}O$ is much smaller than that of $H_2{}^{16}O$, the $H_2{}^{18}O$ lines can trace deeper into the disk and thus they are potentially better probes of the exact position of the H_2O snowline in disk midplane.

Keywords. astrochemistry— protoplanetary disks— ISM: molecules— sub-millimeter: planetary systems— stars: formation—

Observationally locating the position of the H_2O snowline in protoplanetary disks is crucial for understanding the planetesimal and planet formation processes, and the origin of water on the Earth. The velocity profiles of emission lines from disks are usually affected by doppler shift due to keplerian rotation. Therefore, the line profiles are sensitive to the radial distribution of the line emitting regions. However, water lines which have been observed by previous infrared spectroscopic observations (*Spitzer* and *Herschel*, see, e.g., van Dishoeck *et al.* 2014) mainly traced the disk surface and the cold water resevoir outside the H_2O snowline. Thus, they are not good direct tracer of the H_2O snowline.

In our studies (Notsu *et al.* 2016, Notsu *et al.* 2017, Notsu *et al.* 2018), on the basis of our calculations of disk chemical structures and water line profiles, we proposed how to identify the position of the H_2O snowline directly by analyzing the Keplerian profiles of water lines which can be obtained by high dispersion spectroscopic observations across

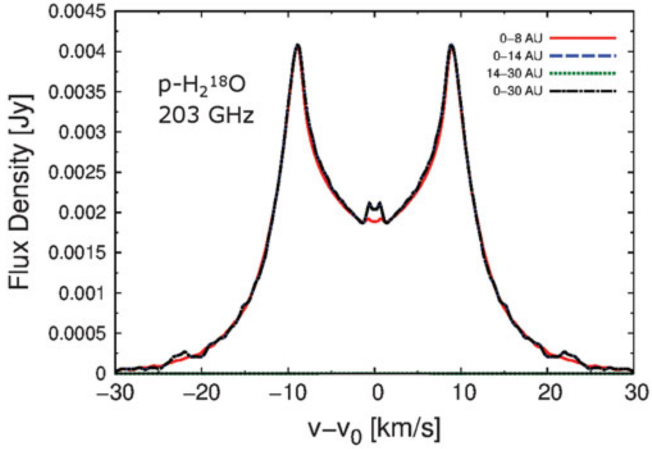

Figure 1. The profile of para-$H_2{}^{18}O$ 203 GHz line for the Herbig Ae disk. In this line profile, we ignore dust emission and adopt a disk inclination, $i = 30$ deg and the distance to the object, $d = 140$ pc. The line profile from inside 8 au (=the inner high temperature region) is displayed with *red solid line*, that from within 14 au (∼within the H_2O snowline) is *blue dashed line*, that from 14-30 au (∼outside the H_2O snowline) is *green dotted line*, and that from the total area inside 30 au is *black dashed dotted line*.

a wide range of wavelengths (from mid-infrared to sub-millimeter, e.g., ALMA, SPICA). We selected candidate water lines to locate the H_2O snowline based on specific criteria. We concluded that lines which have small Einstein A coefficients (A_{ul}=$10^{-6} \sim 10^{-3}$ s^{-1}) and relatively high upper state energies ($E_{up}\sim$ 1000K) trace the hot water reservoir within the H_2O snowline, and can locate the position of the H_2O snowline (see Figure 1). In these candidate water lines, the contribution of the optically thick hot midplane inside the H_2O snowline is large compared with that of the outer optically thin surface layer. This is because the intensities of lines from the optically thin region are proportional to the Einstein A coefficient. Moreover, the contribution of the cold water reservoir outside the H_2O snowline is also small, because lines with high excitation energies are not emitted from the regions at a low temperature.

The position of the H_2O snowline of a Herbig Ae disk exists at a larger radius compared with that around less massive and cooler T Tauri stars. Therefore, it is expected to be easier to observe the candidate water lines, and thus identify the location of the H_2O snowline, in Herbig Ae disks. In addition, since the number densities of the ortho- and para-$H_2{}^{18}O$ molecules are about 1/560 times smaller than their ^{16}O analogues, they trace deeper into the disk than the ortho-$H_2{}^{16}O$ lines, and lines with relatively smaller upper state energies (∼ a few 100K) can also locate the position of the H_2O snowline. Thus these $H_2{}^{18}O$ lines are potentially better probes of the position of the H_2O snowline at the disk midplane, depending on the dust optical depth (Notsu *et al.* 2018).

There are several candidate water lines that trace the position of the H_2O snowline in ALMA Bands 5 − 10. Finally, we have proposed the water line observations for a Herbig Ae disk HD163296 in ALMA Cycle 3, and partial data were delivered. We constrain the line emitting region (the location of the H_2O snowline) and the mm dust opacity from the observations (Notsu *et al.* 2019).

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