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ABSTRACT

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Water vapor in protoplanetary disks outside 30 AU: Herschel and ALMA

Inside protoplanetary disks, gas-phase water is expected to show large abundances variations. In warm regions (T>200 K), rapid gas-phase chemical reactions lock up all available oxygen into water with peak H2O/H2 values of $\sim 10^{-4}$. However, most of the disk is much colder and water is expected to freeze out rapidly onto dust grains beyond the "snow-line". But sufficient stellar ultraviolet radiation penetrates the layers above the disk's midplane, and desorbs water off icy grains back into the gas phase. Recent laboratory experiments show this process to be very efficient and capable of explaining the observed warm water vapor in the inner disks (<30 AU). Here, abundant water can shield itself against photodissociation by the stellar ultraviolet radiation, while in the outer disk appreciable gas-phase water is expected in spite of low temperatures (T<<100 K).

We will present recent Herschel observations of cold water vapor that paint a very different picture. These HIFI observations, obtained by the "Water in Star Forming Regions'" (WISH) Key Program, of the ground-state transitions of ortho- and para-H2O reveal surprisingly weak lines and tight upper limits, factors 10-50 below the values expected from the ease of water ice formation on grain surfaces and the efficient H2O photo-desorption mechanism. We argue that a vertical "cold finger'" effect can "freeze dry" disks: icy grains coagulate more easily, and larger grains are expected to settle more efficiently to the disk midplane as commonly observed. This reduces the ice content of the higher disk layers subject to ultraviolet irradiation and water photodesorption. We conclude that as much as 95-99% of the ice-carrying grains may have settled disk midplane. These observations of cold water vapor therefore may tell us something fundamentally new about the coupled structure, dynamics, and chemistry of the outer disk.

Herschel cannot spatially resolve the H2O emission (although HIFI provides superb velocity resolution), but ALMA can. Generally water lines are blocked by the atmosphere. However, the H2O 313-202 line at 183.5 GHz is observable with ALMA band 5. We present model calculations that show that ALMA will be able to image water vapor emission in disks using this transition offering a powerful new probe of disk chemistry and structure.