Rotational Line Emission from Water in Protoplanetary Disks

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Introduction

Gas phase water is expected to be abundant between the water-ice sublimation temperature T~110-170 K and the dissociation temperature T~2500 K. Its rich spectrum covers almost all wavelength bands. Warm water has been observed in the near-infrared near 2.3μm at temperatures T > 1200 K and radii R < 0.4 AU, and also in the mid-infrared with *Spitzer.* The far-infrared spectrometers aboard the *Herschel* space telescope will allow studies of the pure rotational H_2O lines characteristic of gas temperatures T>60 K. We will show that several water lines can be detected by *Herschel* at very low abundances close the mid-plane, where the bulk of the water is frozen out to radii R~100 AU. These lines will complement measurements of the near- and mid-infrared water lines.

Models

The calculation is done as follows:

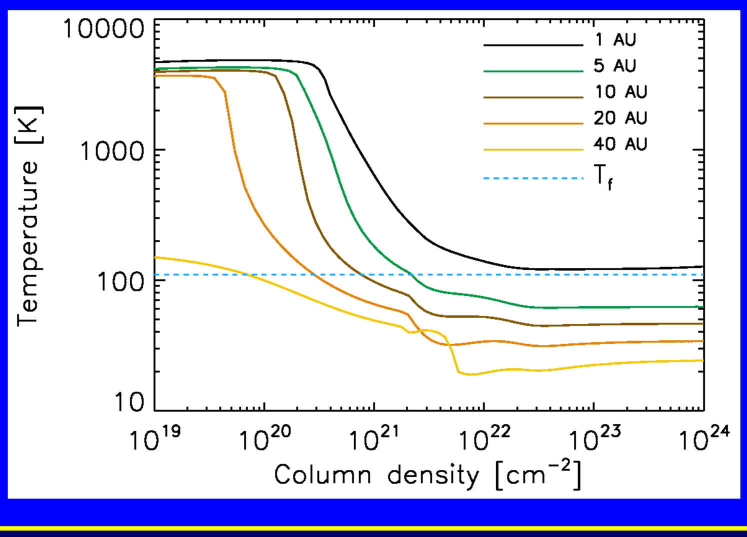
1) We use an X-ray irradiated disk code to calculate the temperature structure and molecular abundances for a generic T-Tauri disk.

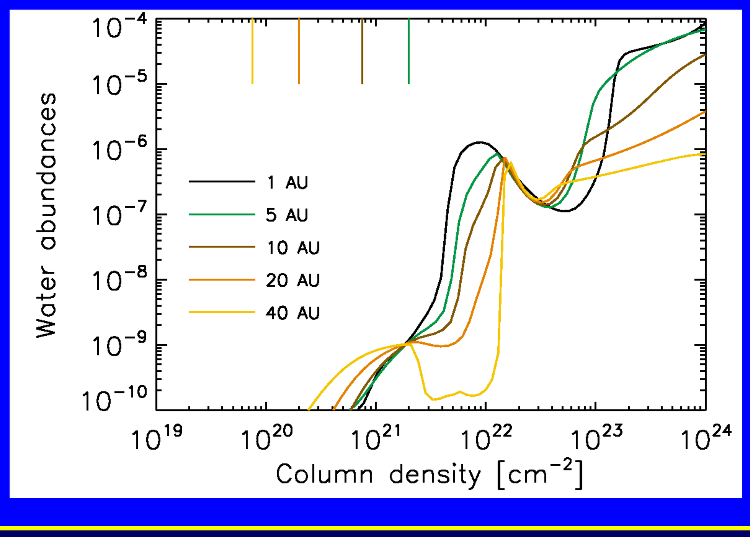
2) The results are input into a multi-zone radiative transfer code that calculates the excitation of H_2O lines.

3) A ray tracing code is used to obtain line fluxes and line shapes.

The thermal and chemical structure of the disk

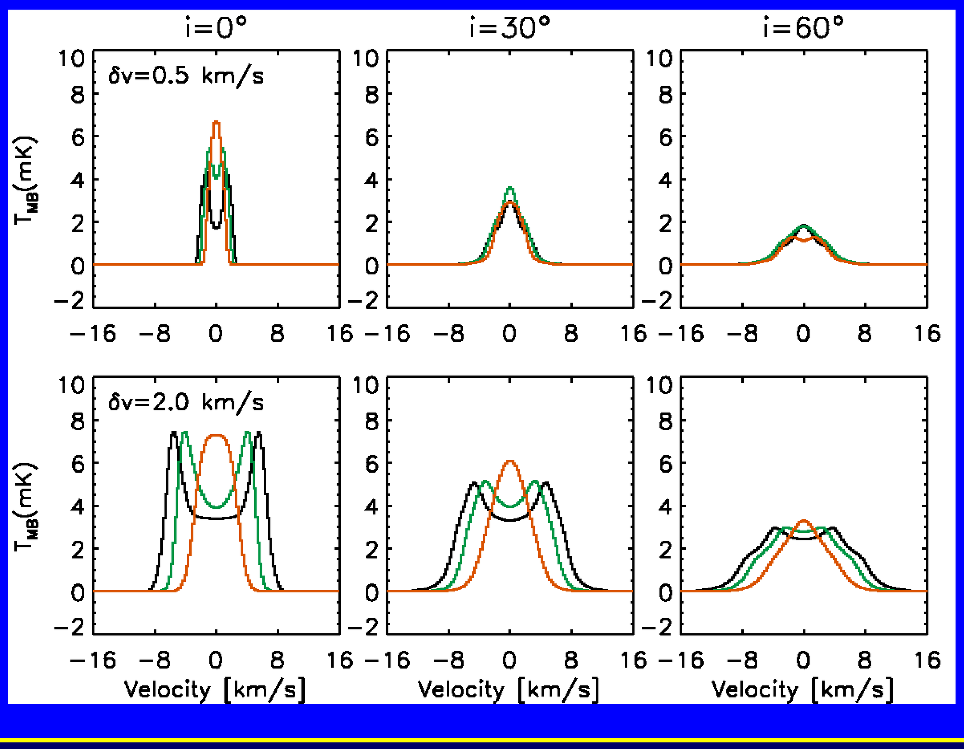
The disk is illuminated by stellar X-rays with a thermal spectrum T_x = 1 keV and luminosity L_x = 2 x 10^{30} erg/s. The density structure is given by the generic T Tauri disk model with accretion rate dM/dt=10^{-8} M(Sun)/yr and stellar parameters M_*=0.5 M(Sun), R_*=2 R(Sun), and T_*=4000 K. The temperature and water abundances are shown as a function of perpendicular column densities. The freeze-out temperature for water, T_f=110 K, is indicated with a blue line.





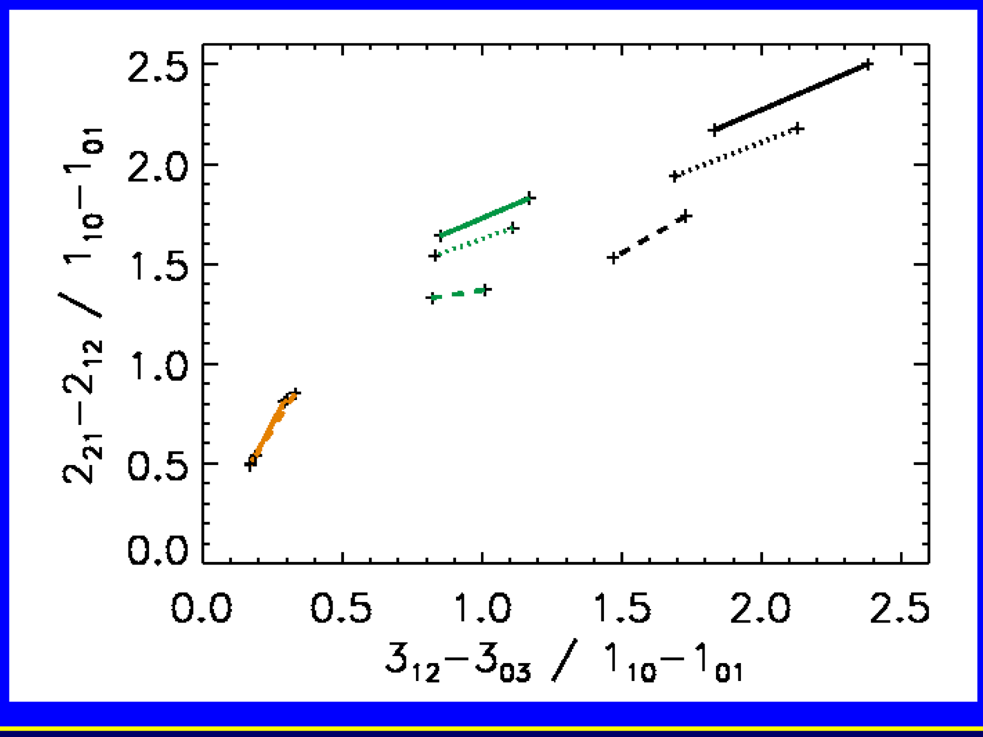
The 1_{10}-1_{01} ortho-H_2O line profiles

The line profiles are calculated: (a) No freeze-out below T_f (black), a residual water abundance of (b) x(H_2O)=10^{-8} (green) and (c) x(H_2O)=10^{-10} (orange). Three inclinations, 0°, 30°, and 60°, and two turbulent velocities, 0.5 and 2.0 km/s are shown.



Line ratios

The ground 1_{10}-1_{01} ortho- and 1_{11}-0_{00} para-H_2O lines do not provide information on the residual water in the freeze-out zone of the disk. Therefore, it is preferred to observe lines with higher excitation temperatures. Unfortunately the sensitivity of HIFI at higher frequencies is such that only line intensities can be obtained within a reasonable amount of observing time. Here we show the 3_{12}-3_{03} / 1_{10}-1_{01} vs. 2_{21}-2_{12} / 1_{10}-1_{01} line ratios. The combination clearly distinguishes between different residual water abundances. The colour indices are the same as for the line profiles.



Conclusions

- The ground 1_{10}-1_{01} ortho- and 1_{11}-0_{00} para-H_2O transitions will provide information on the extend of water, and the amount of turbulence in a protoplanetary disk.
- Line ratios of the ortho- and para-H2O line transition are constant, ~0.6, for models with and without freeze-out and do NOT provide information on the amount of water in the disk.
- The 3_{12}-3_{03} / 1_{10}-1_{01} vs. 2_{21}-2_{12} / 1_{10}-1_{01} line ratios distinguish between the different residual water abundances in the freeze-out zone.
- The rotational lines to be observed with *Herschel* will complement the near- and mid-infrared lines probing the warm inner regions, R < 2.0 AU, of protoplanetary disks.

Future work

- We will extend our study to the ro-vibrational H_2O transitions to study the warm inner regions of disks around 6μm (observable with SOFIA), which are both collisionally and fluorescently excited.
- This will allow the direct study of the location of the snow-line in protoplanetary disks.

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References:
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