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Modelling water in the envelopes of low-mass protostars

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Abstract. Using sophisticated spherically symmetric radiative transfer models for gas and dust, we simulate the emission of H_2O and its isotopes for the circumstellar envelopes around class 0 protostars, as preparatory science for the ESA cornerstone mission Herschel and its spectrometer, HIFI. L483mm is taken as an example. We probe a wide range of models in which dust, freeze-out and a large variety of abundance structures and optical depths are taken into account. A sample of water lines is selected that are observable by Herschel. Expected fluxes for these lines are derived from the models, convolved with the Herschel beam size.

1. Introduction

Water has been detected by the LWS instruments aboard ISO in low-mass protostars (e.g. Ceccarelli et al. 1999, Giannini et al. 2001). The origin of the water lines is still subject of discussion, however. It has been theorized to originate in both the outflow and the quiescent infalling envelope. Ceccarelli et al. (1999) place the water in the small (200 AU), dense ($> 10^7 \mathrm{cm}^{-3}$) and warm ($>$ 100 K) region of the protostellar envelope. The ESA Herschel mission and in particular the HIFI instrument are particularly well suited to observe rotational far-infrared and submillimeter water lines in these environments and test the various models.

2. Approach

We started with the physical structure deduced by Jørgensen (2004) for L483mm ($L_{\mathrm{bol}} = 9L_{\odot}$, $M_{\mathrm{env10K}} = 4.4M_{\odot}$, D=200 pc), giving the density and temperature profiles for a typical protostellar envelope. These profiles are the result of a dust radiative transfer calculation with DUSTY (Ivezić & Elitzur, 1997). The line radiative transfer is subsequently calculated through RATRAN, developed by Hogerheijde & van der Tak (2000). The dust to gas ratio has been set at 1:100, the dust opacities are approximated by the OH5 (Ossenkopf & Henning 1994) at a density of $10^6 \mathrm{cm}^{-3}$.

To simulate the abundance of the water molecule, we have used trial abundances with the assumption that water freezes out onto the dust grains below 90 K (Boonman et al. 2003) (Figure 1). Currently no velocity profile except a turbulent line width of 0.8 km/s is included in the models. The trial abundances range from 10^{-8} to 10^{-6} in the region with $T < 90$ K (X_{d}) and from 10^{-6} to 10^{-4} for the region with $T > 90$ K (X_0, both relative to the H_2 abundance). Using RATRAN one can simulate the predicted line profiles and fluxes, convolved with the Herschel beam. We consider all lines observable by HIFI, except those which are likely to maser.

3. Results

The line fluxes of water depend strongly on the abundances in both regions as seen in Figure 2. Results for optically thin isotopes such as $H_2^{18}O$ show that the excited lines are sensitive to the region with $T > 90$ K, so these lines would be well suited to probe X_0 in the inner regions.

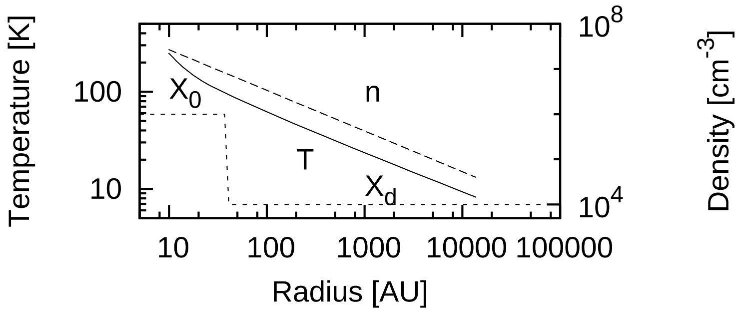

Figure 1. The physical strucure of the protostellar envelope of L483mm. The solid line represents the temperature, the dashed line is the molecular hydrogen density and the dotted line represents the H_2O abundance structure.

The ground-state ortho- and para-water lines are more sensitive to the outer abundance $X_{\rm d}$ and also start to become optically thick ($\tau \approx 12$). Note that the antenna temperatures are very low, however, only tens of mK, so that long integration times are needed. The lines for main isotope H_2O are in general much stronger but are optically thick for all models, except the highest excitation lines. This means that these lines depend on both X_0 and $X_{\rm d}$ abundances, which are less easy to disentangle. The next step is to look into the velocity profiles of infall and outflow and compare the lines again.

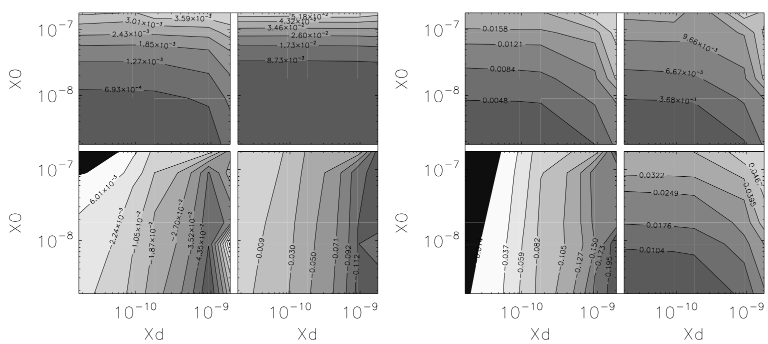

Figure 2. Contour plots of fluxes of selected ortho-$H_2^{18}O$ (*left*) and para-$H_2^{18}O$ (*right*) lines for a range of X_0 and $X_{\rm d}$ abundances. The contour levels indicate the antenna temperatures in the Herschel beam. The ortho-lines are $1_{10} - 1_{01}$ (*lower left*), $2_{12} - 1_{01}$ (*lower right*), $2_{21} - 2_{12}$ (*upper left*) and $3_{12} - 2_{21}$ (*upper right*). The para-lines are $1_{11} - 0_{00}$ (*lower left*), $2_{02} - 1_{11}$ (*lower right*), $2_{11} - 2_{02}$ (*upper left*) and $2_{20} - 2_{11}$ (*upper right*)

Keywords. Herschel,HIFI, water, stars:formation, ISM: molecules

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