Deuterated water in low-mass protostars

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ABSTRACT

Water is a key molecule in the interstellar medium by its role in the oxygen chemistry, in the cooling of warm gas in star-forming regions and in the appearance of life. The HDO/H_2O ratio is a useful tool to understand the mechanisms of water formation as well as how water has evolved from cold prestellar cores to protoplanetary disks and consequently to form oceans for the Earth's specific, but probably not isolated, case. Numerous HDO, $H_2{}^{18}O$ and D_2O transitions were observed with single-dish telescopes (Herschel/HIFI, IRAM-30m, JCMT, APEX) towards several Class 0 protostars (IRAS16293-2422, NGC1333 IRAS4A and IRAS4B). These observations are compared with predictions from radiative transfer models and give strong constraints on the determination of the deuterium fractionation of water in this kind of sources.

OBSERVATIONS with single-dish telescopes (Herschel/HIFI, IRAM-30m, JCMT, APEX)

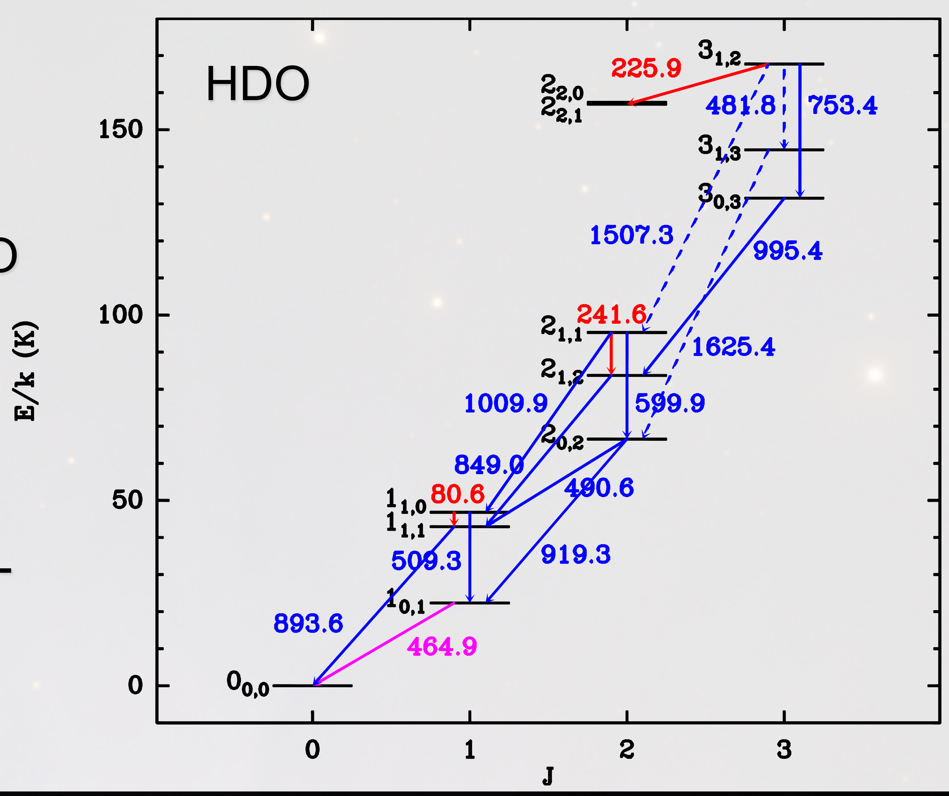
✦ ***IRAS 16293-2422***

2 spectral surveys TIMASSS ([1]) and CHESS ([2]) : detection of 13 HDO, 5 $H_2{}^{18}O$ (used to estimate the water abundances : $^{16}O/^{18}O \sim 500$) and 3 D_2O lines

✦ ***NGC1333 IRAS4A and IRAS4B :***

HIFI lines with the CHESS/WISH/HEXOS ([2,3,4]) consortium + ground-based observations

4 HDO detected lines + 2 upper limits



MODELING

✦ Analysis with the **CASSIS** software ([5])

✦ ***Estimates of the abundances in the protostellar envelope***

Modeling with the 1D radiative transfer **RATRAN** code ([6]) using :

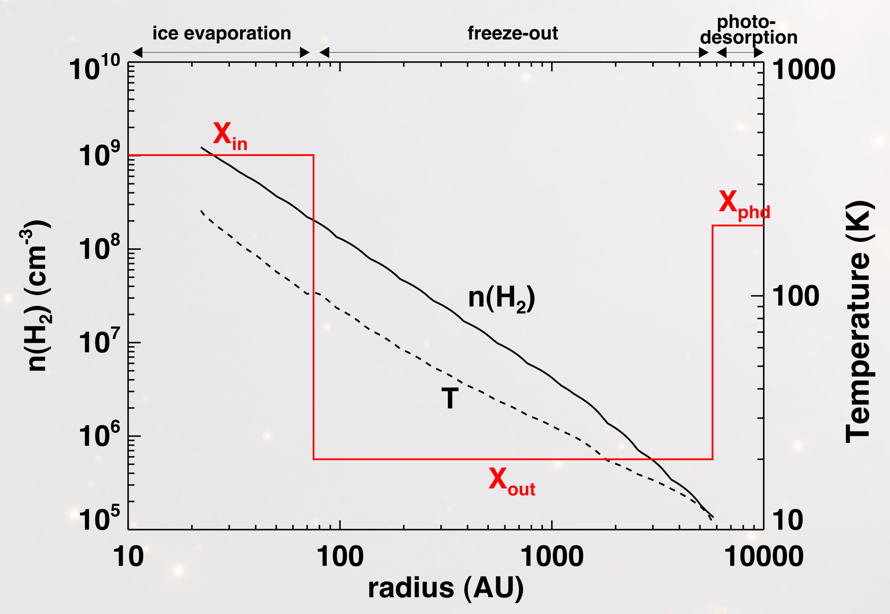
- a source structure ([7,8])
- an abundance jump at 100 K (sublimation of the ice mantles)
- collisional coefficients of HDO/D_2O calculated for ortho and para-H_2 ([9,10,11])

Grids of models with different inner abundance (X_{in}) and outer abundance (X_{out}) were run. The best-fit is determined by χ^2 minimization by comparison with the observed line profiles.

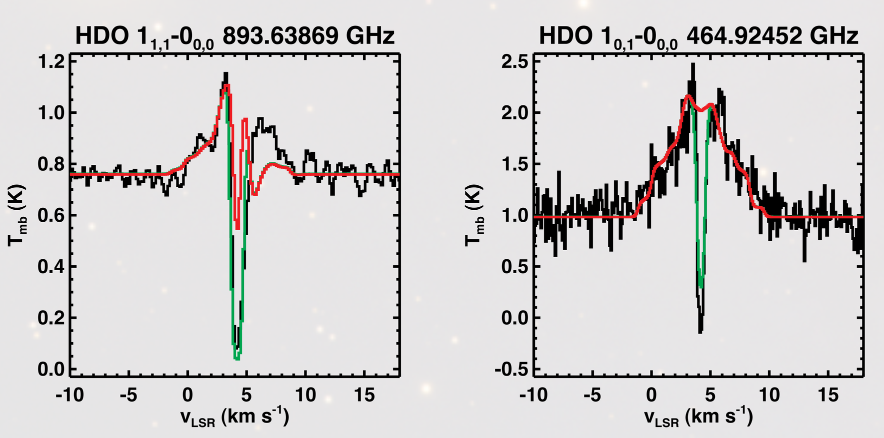
✦ ***Estimates of the abundances in the outflows***

Modeling with the radiative transfer **RADEX** code ([12])

PRESENCE OF A WATER-RICH ABSORBING LAYER IN THE SURROUNDINGS OF LOW-MASS PROTOSTARS

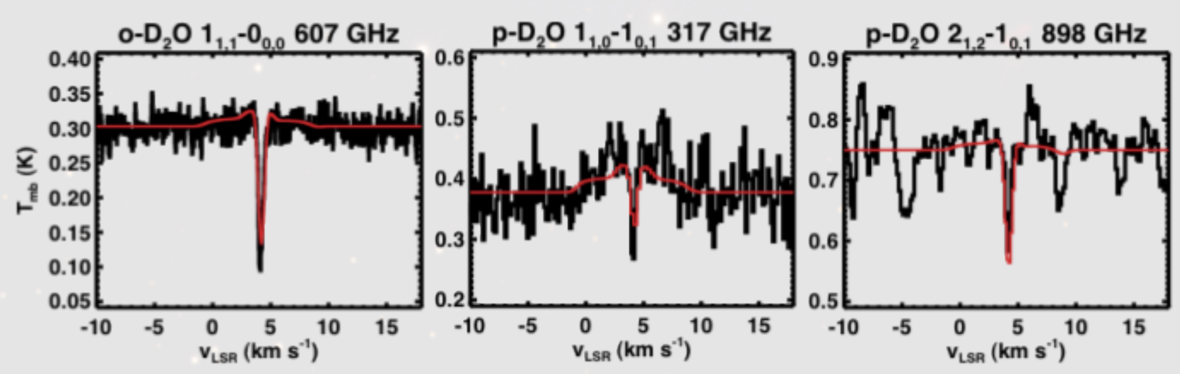


- required to reproduce the absorption components seen on the HDO and D_2O fundamental lines
- $N(HDO) = 2.3 \times 10^{13}$ cm^{-2} in the absorbing layer of IRAS 16293 ([13])



In black : *observations of the HDO fundamental transitions in IRAS16293-2422.* ***In red :*** *modeling without adding the absorbing layer* ***In green :*** *modeling with the absorbing layer*

- $N(D_2O) = 2.5 \times 10^{12}$ cm^{-2} in the absorbing layer of IRAS 16293 with ortho/para(D_2O) ~ 1.3 ([14,15])

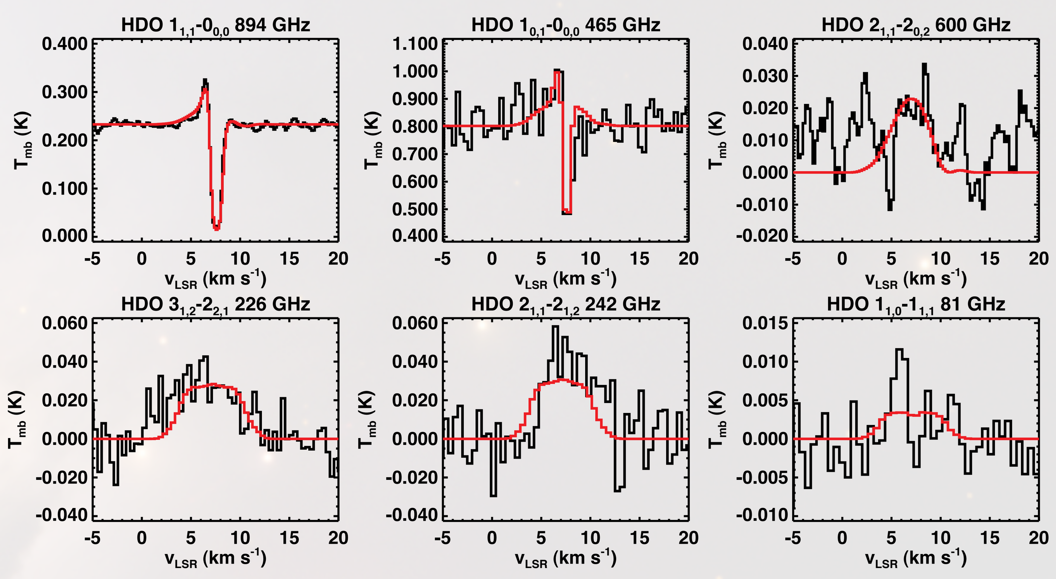


In black : *observations of the D_2O fundamental transitions in IRAS16293-2422.*
In red : *modeling adding an absorbing layer*

- $N(HDO) = 1.4 \times 10^{13}$ cm^{-2} in the absorbing layer of NGC1333 IRAS4A and IRAS4B ([16])

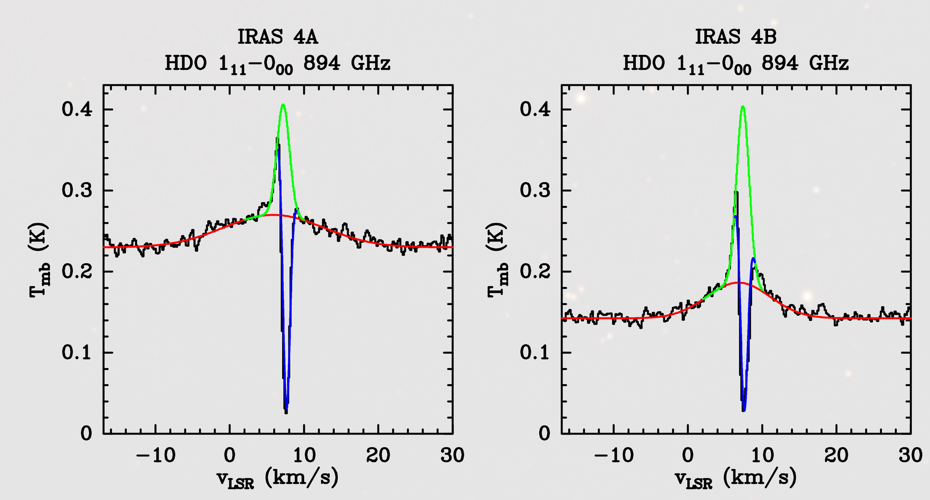
HDO ABUNDANCES IN LOW-MASS PROTOSTARS

Study of HDO in NGC1333 IRAS4A :



In black : *HDO observations towards NGC1333 IRAS4A (the outflow component is subtracted).*
In red : *best-fit model obtained with RATRAN.*

Broad outflow component observed on the HDO fundamental transitions towards NGC1333 IRAS4A and IRAS4B :



Source	Inner abundance	Outer abundance	Absorbing layer N(HDO) (cm^{-2})	Outflow abundance	References
NGC 1333 IRAS 4A	$7.5^{+3.5}_{-3.0} \times 10^{-9}$	$1.2^{+0.6}_{-0.4} \times 10^{-11}$	1.4×10^{13}	$0.7 - 1.9 \times 10^{-9}$	Coutens et al. (in prep)
NGC 1333 IRAS 4B	$1.0^{+1.8}_{-0.9} \times 10^{-8}$	$1.2^{+0.6}_{-0.4} \times 10^{-10}$	1.4×10^{13}	–	Coutens et al. (in prep)
NGC 1333 IRAS 2A	$8^{+2.0}_{-1.2} \times 10^{-8}$	$7^{+11}_{-6.1} \times 10^{-10}$	–	–	Liu et al. (2011)
IRAS 16293-2422	$1.8^{+0.6}_{-0.4} \times 10^{-7}$	$8^{+2.0}_{-3.4} \times 10^{-11}$	2.3×10^{13}	–	Coutens et al. (2012, 2013)
L1448-mm	4×10^{-7}	–	–	–	Codella et al. (2010)

HDO/H_2O RATIOS in NGC1333 IRAS4A/B

✦ ***Hot corinos :***

$N(H_2O)$ estimated in the hot corinos of these two sources using interferometric observations of the para-$H_2{}^{18}O$ $3_{1,3}$-$2_{2,0}$ line at 203 GHz ([17,18])

Using the N(HDO) derived with RATRAN, it leads to :

$HDO/H_2O = 4 \times 10^{-4} - 3.0 \times 10^{-3}$ in IRAS 4A ([16])
$HDO/H_2O = 1 \times 10^{-4} - 3.7 \times 10^{-3}$ in IRAS 4B ([16])

- lower than estimates by Taquet et al. 2013 ([19])
- in agreement with estimates by Persson et al. 2013 ([20])

✦ ***Outer envelope and absorbing layer :***

Analysis of water by the WISH team in progress

✦ ***Outflows emanating from IRAS4A :***

$HDO/H_2O = 1 \times 10^{-3} - 9 \times 10^{-2}$ in the red outflow
$HDO/H_2O = 7 \times 10^{-4} - 6 \times 10^{-2}$ in the blue outflow

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