Deuterated water in low-mass protostars : NGC 1333 IRAS 4A/4B and IRAS 16293-2422

Audrey COUTENS

## Deuterated water in NGC 1333 IRAS 4

Fréquence	$J_{ m Ka,Kc}$	$E_{ m up}/k$	$A_{ij}$	Télescope	Lobe				
(GHz)		(K)	$(s^{-1})$		(")				
NGC 1333 IRAS 4A									
80.5783	$1_{1,0}$ - $1_{1,1}$	47	$1.32 \times 10^{-6}$	IRAM-30m	31.2				
225.8967	$3_{1,2}$ - $2_{2,1}$	168	$1.32 \times 10^{-5}$	IRAM-30m	11.1				
241.5616	$2_{1,1}$ - $2_{1,2}$	95	$1.19 \times 10^{-5}$	IRAM-30m	10.4				
464.9245	$1_{0,1}$ - $0_{0,0}$	22	$1.69 \times 10^{-4}$	JCMT	10.8				
599.9267	$2_{1,1}$ - $2_{0,2}$	95	$3.45 \times 10^{-3}$	HIFI 1b	35.9				
893.6387	$1_{1,1}-0_{0,0}$	43	$8.35 \times 10^{-3}$	HIFI 3b	24.1				
	Flot	de NGC	C 1333 IRAS	4A					
599.9267	Flot 0 2 <sub>1,1</sub> -2 <sub>0,2</sub>	de NGC 95	$\frac{1333 \text{ IRAS}}{3.45 \times 10^{-3}}$	4A HIFI 1b	35.9				
599.9267 893.6387	$\begin{array}{c} Flot \\ 2_{1,1}-2_{0,2} \\ 1_{1,1}-0_{0,0} \end{array}$	<mark>de NGC</mark> 95 43	$\begin{array}{c} \hline \textbf{C} \ \textbf{1333} \ \textbf{IRAS} \\ 3.45 \times 10^{-3} \\ 8.35 \times 10^{-3} \end{array}$	4A HIFI 1b HIFI 3b	35.9 24.1				
599.9267 893.6387	Flot o 2 <sub>1,1</sub> -2 <sub>0,2</sub> 1 <sub>1,1</sub> -0 <sub>0,0</sub>	de NGC 95 43 IGC 133	$\begin{array}{c} \hline 1333 \text{ IRAS} \\ 3.45 \times 10^{-3} \\ 8.35 \times 10^{-3} \\ \hline 33 \text{ IRAS 4B} \end{array}$	4A HIFI 1b HIFI 3b	35.9 24.1				
599.9267 893.6387 225.8967	$\frac{\text{Flot}}{2_{1,1}-2_{0,2}}$ $1_{1,1}-0_{0,0}$ $N$ $3_{1,2}-2_{2,1}$	de NGC 95 43 IGC 133 168	$\begin{array}{c} \hline 1333 \text{ IRAS} \\ 3.45 \times 10^{-3} \\ 8.35 \times 10^{-3} \\ \hline 33 \text{ IRAS 4B} \\ 1.32 \times 10^{-5} \end{array}$	4A HIFI 1b HIFI 3b IRAM-30m	35.9 24.1 11.1				
599.9267 893.6387 225.8967 241.5616	$\frac{\text{Flot}}{2_{1,1}-2_{0,2}}$ $1_{1,1}-0_{0,0}$ $N$ $3_{1,2}-2_{2,1}$ $2_{1,1}-2_{1,2}$	de NGC 95 43 IGC 133 168 95	$\begin{array}{c} \hline 1333 \text{ IRAS} \\ \hline 3.45 \times 10^{-3} \\ \hline 8.35 \times 10^{-3} \\ \hline 33 \text{ IRAS 4B} \\ \hline 1.32 \times 10^{-5} \\ \hline 1.19 \times 10^{-5} \\ \hline \end{array}$	4A HIFI 1b HIFI 3b IRAM-30m IRAM-30m	35.9 24.1 11.1 10.4				
599.9267 893.6387 225.8967 241.5616 464.9245	$\frac{\text{Flot}}{2_{1,1}-2_{0,2}}$ $1_{1,1}-0_{0,0}$ $N$ $3_{1,2}-2_{2,1}$ $2_{1,1}-2_{1,2}$ $1_{0,1}-0_{0,0}$	de NGC 95 43 IGC 133 168 95 22	$\begin{array}{c} \hline 1333 \text{ IRAS} \\ \hline 3.45 \times 10^{-3} \\ \hline 8.35 \times 10^{-3} \\ \hline 33 \text{ IRAS 4B} \\ \hline 1.32 \times 10^{-5} \\ \hline 1.19 \times 10^{-5} \\ \hline 1.69 \times 10^{-4} \\ \end{array}$	4A HIFI 1b HIFI 3b IRAM-30m IRAM-30m CSO	35.9 24.1 11.1 10.4 16.5				
599.9267 893.6387 225.8967 241.5616 464.9245 599.9267	$\frac{\text{Flot}}{2_{1,1}-2_{0,2}}$ $1_{1,1}-0_{0,0}$ $N$ $3_{1,2}-2_{2,1}$ $2_{1,1}-2_{1,2}$ $1_{0,1}-0_{0,0}$ $2_{1,1}-2_{0,2}$	de NGC 95 43 IGC 133 168 95 22 95	$\begin{array}{c} \hline 1333 \text{ IRAS} \\ \hline 3.45 \times 10^{-3} \\ \hline 8.35 \times 10^{-3} \\ \hline 33 \text{ IRAS 4B} \\ \hline 1.32 \times 10^{-5} \\ \hline 1.19 \times 10^{-5} \\ \hline 1.69 \times 10^{-4} \\ \hline 3.45 \times 10^{-3} \\ \end{array}$	4A HIFI 1b HIFI 3b IRAM-30m IRAM-30m CSO HIFI 1b	35.9 24.1 11.1 10.4 16.5 35.9				





v<sub>LSR</sub> (km/s)

HDO Meeting - Garching 15/01/2013

## Deuterated water in NGC 1333 IRAS 4

#### RATRAN modeling

Subtraction of the broad outflow component present on the observations of the fundamental transitions :

FWHM ~ 16 km/s for IRAS 4A FWHM ~ 10 km/s for IRAS 4B

• Density and temperature profiles determined by Kristensen et al. (2012)

▶ Velocity profiles: vr = √(2GM\*/r) IRAS 4A : M\* = 0.5 M<sub>sol</sub> (Maret et al. 2005, di Francesco et al. 2001) IRAS 4B : M\*? free parameter



# HDO modeling in NGC 1333 IRAS 4A

Adding an absorbing layer is needed to reproduce the absorption lines at 894 and 465 GHz :  $N(HDO)_{abs} \sim 1.4 \times 10^{13} \text{ cm}^{-2}$ 





5

What about H<sub>2</sub>O? ▶ Comparison of the HDO/H<sub>2</sub>O ratios with the interferometric results

tems viewed edge on show broader lines and no velocity aradi- is assumed appending think the interview of the state of the ent (case B in Fig. 6). The dynamical structure of the disk would (validnging eithet the convertion of zer move towards a rotationally supported disk on a local dynamicalitions scale outhich, isnarterne Splical rating the hill an glates citation we dealer we wanter his tyme (Brunchschowler Hagreement with the suggestion by Watson et al. (2007) (case A in Fig. 6). In IRAS2A and IRAS4A-NW, the ge is closer to edge on causing mid IK emission to asing origin of Hove emission by the optically thick envelope (case B in Fig. 6). We notigent when a new doal to extend to the matrice to as a distinct operation of the section o sestilete diata's and streas the anglitate should be added by any tobas severation on the section and the section of the secti

beprinsted of the expitations of the

to thank the directed up or whatson et al.

gas phase water in IRAS2A is

IRAS ALTING BOD times h

er is present in the inner pa

Tablen4detectionizes dRAssered to

lengths is the to the high do the

a strong Muthow Contribution X0H

 $X(=N_{\rm H_{2}O}/N_{\rm H_{2}})$  4.2×10<sup>-6</sup>

0.61

1994). The massa of gas phase in the bottom of Table 4, in unit PHILAB SHILL <sup>18</sup>emtestser Briff Frig. 6). Infre Bynkan bearvarstere briffik Hists wulkta- along with the freetion of gass of tefnobsets alles from the same way and the reactest of a statistic of the pointed of the busic of the fines of casal fambles can wanter is an etway of the free of a matices of the busic of the derived column density of H maninestopal 2003) H<sup>16</sup>O (Cernicharo et al. 1994). Several ob- than deduced by Watson servables argue against that the  $H_1^{18}O_{31,3} - 2_{2,0}$  line is masing in gas phase when  $H_2^{18}AS_{18}AS_{18}AS_{18}$  the sources investigated here we have investigated here we have here the sources investigated here we have here the sources investigated here we have here we have

the sources investigated brancher prise of = 0.8 . e0-=0.0 ter ie orean the inner parts First. the inference in the central beam to be served in the central beam to be served in the second second served in the second se wWelstere to continue attentionate tare beamingal ribbal to the late parted non-determined in RAS4 & hit RIR specied inteache officequentranglysis which also ta for unes I an Ats a (Joreness in called a strong sources and strong and the second and the Herczeglet and OUL). wither stand with the stand in IRAS2A and IRAS4A-NW compared the RIANSARK CREVE STR about the Head the Hose RANALS Hathis Context ds

# HDO modeling in NGC 1333 IRAS 4A



#### **OUTFLOWS**

profiles of the broad component compared with other molecules tracing the outflows

 similarity between the HDO and CO line profiles

▶ RADEX modeling used with the excitation conditions derived by Yildiz et al. (2012) for CO :  $n(H_2) \sim 3 \times 10^5$  cm<sup>-3</sup>, T ~ 100 - 150 K

▶ N(HDO) ~ 2 - 4 x 10<sup>13</sup> cm<sup>-2</sup>

X(HDO) ~ 7 x 10<sup>-10</sup> - 1.9 x 10<sup>-9</sup> using N(H<sub>2</sub>) ~ 2.1 - 2.8 x 10<sup>22</sup> cm<sup>-2</sup> (Yildiz et al. 2012)

• Estimation of the HDO/H<sub>2</sub>O ratio in the outflows?

## HDO modeling in NGC 1333 IRAS 4B

vr = √(2GM\*/r) with M\* ?
grid with 3 parameters: X<sub>in</sub>, X<sub>out</sub>, M\*
absorbing layer N(HDO) ~ 1.4 x 10<sup>13</sup> cm<sup>-2</sup>



Upper limit on the inner abundance consistent with the undetection of the 226 GHz line with SMA (Jørgensen & van Dishoeck 2010)



HDO Meeting - Garching 15/01/2013

# Deuterated water in NGC1333 IRAS4B

#### **New observations**

#### IRAM-30m observations : 241 GHz line (Eup = 95 K), 81 GHz line (Eup = 47 K) & 226 GHz line (Eup = 170 K)



APEX observations at 465 GHz : proposal accepted, 5 hours observed instead of the 15h required (5σ detection)

Improvement of the modeling with the new observations ?

Add IRAS 4B to the paper about IRAS4A???



## Deuterated water in IRAS16293-2422

### New D<sub>2</sub>O analysis



No prediction of D<sub>2</sub>O absorption lines without adding an absorbing layer to the structure of Crimier et al. (2010)
adding an absorbing layer produces an absorbing line at 898 GHz consistent with observations
N(D<sub>2</sub>O)<sub>abs</sub> = 2.5 x 10<sup>12</sup> cm<sup>-2</sup>

▶ ortho/para (D<sub>2</sub>O)<sub>abs</sub> ~ 1.3





# Deuterated water in IRAS16293-2422

	Hot corino		Outer envelope		Photodesorption layer	
	Best-fit	$3\sigma$	Best-fit	$3\sigma$	$A_V \sim 1 - 4 \text{ mag}$	
HDO <sup>a</sup>	$1.8 \times 10^{-7}$	$1.4 - 2.4 \times 10^{-7}$	$8 \times 10^{-11}$	$5.5 - 10.6 \times 10^{-11}$	$\sim 0.6 - 2.4 \times 10^{-8}$	
$H_2O^{a,b}$	$1 \times 10^{-5}$	$4.7 - 40.0 \times 10^{-6}$	$1.5 \times 10^{-8}$	$7.0 - 22.5 \times 10^{-9}$	$\sim 1.3 - 5.3 \times 10^{-7}$	
$D_2O$	$7 \times 10^{-10}$	$\leq 1.3 \times 10^{-9}$	$5 \times 10^{-12}$	$\leq 1.3 \times 10^{-11}$	$\sim 6.6 - 27 \times 10^{-10}$	
HDO/H <sub>2</sub> O	1.8%	0.4% - 5.1%	0.5%	0.3% - 1.5%	$\sim 4.8\%^{c}$	
D <sub>2</sub> O/HDO	0.4%	$\leq 0.9\%$	6.3%	≤ 23%	~ 10.8% <sup>c</sup>	
D <sub>2</sub> O/H <sub>2</sub> O	0.007%	≤ 0.03%	0.03%	$\leq 0.2\%$	$\sim 0.5\%^{c}$	

