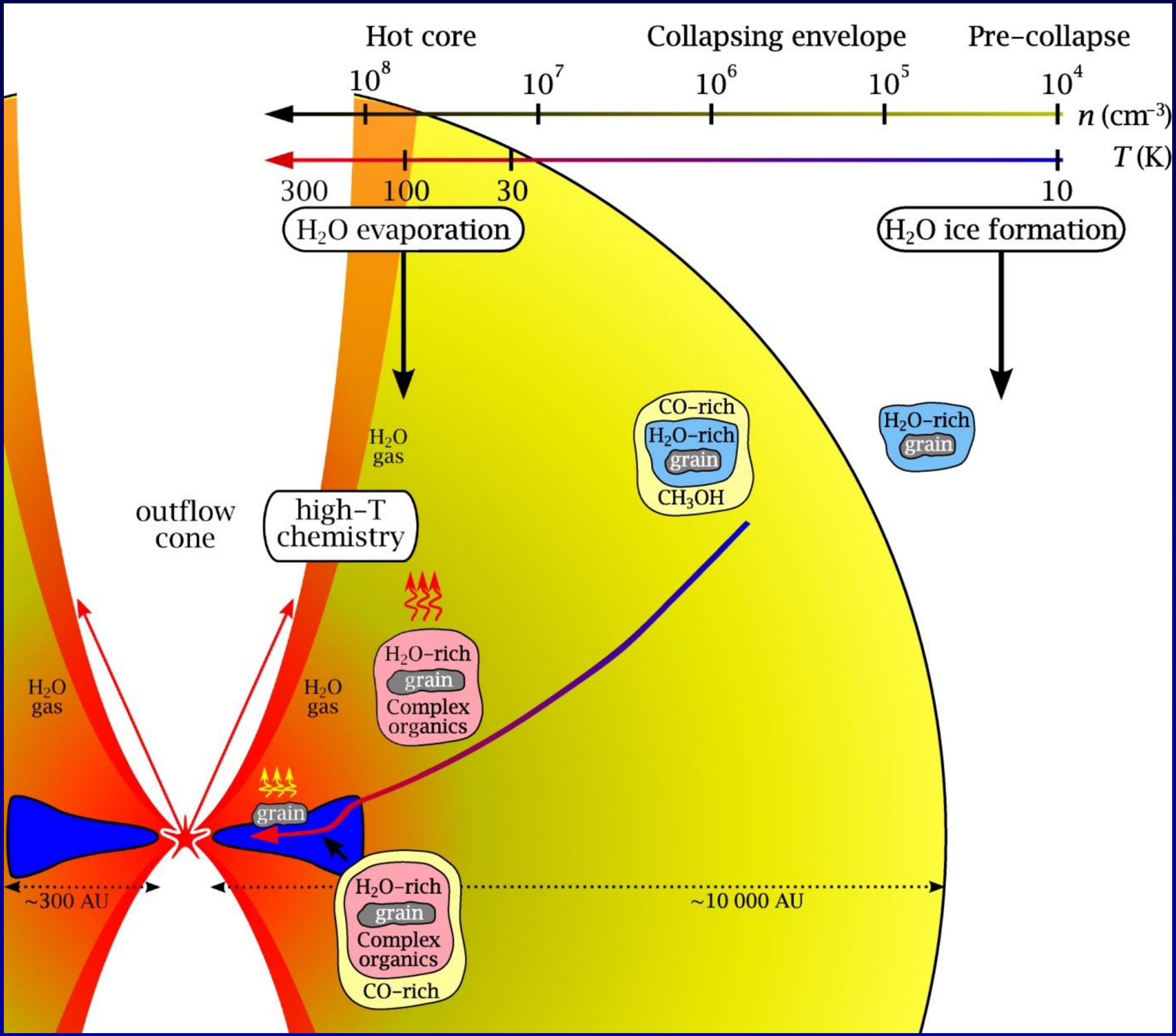
# Goal: follow $HDO/H_2O$ from cores to disks to planets




Visser et al. 2009
Herbst & vD 2009

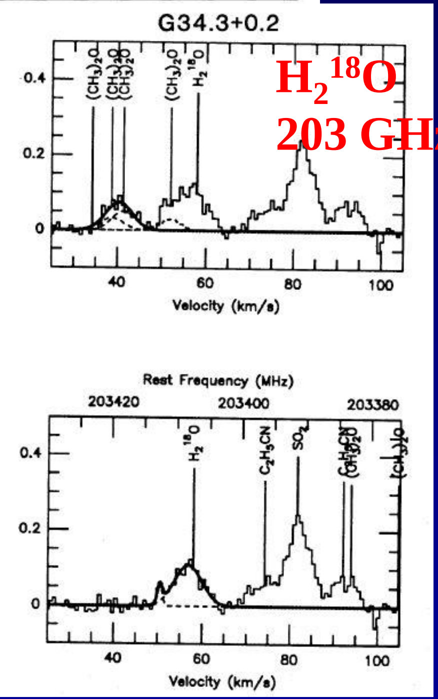
# Early work on HDO/$H_2O$: high mass YSOs

Astron. Astrophys. 228, 447–470 (1990) + 1988

ASTRONOMY AND ASTROPHYSICS

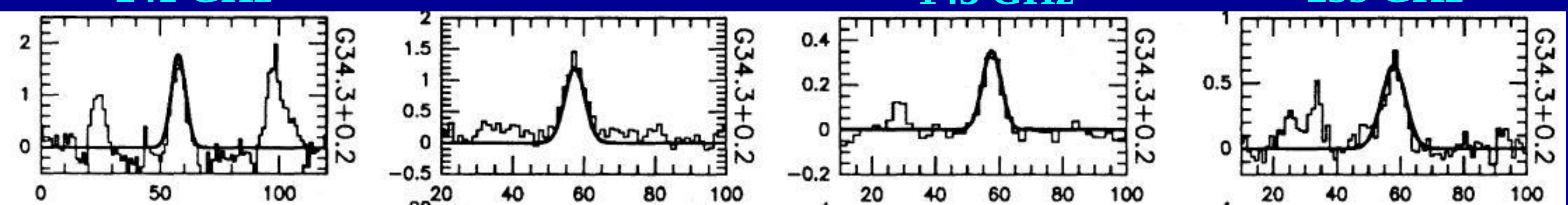
## Deuterated water and ammonia in hot cores

T. Jacq[1,2], C.M. Walmsley[1], C. Henkel[1], A. Baudry[2], R. Mauersberger[1,3], and P.R. Jewell[4]



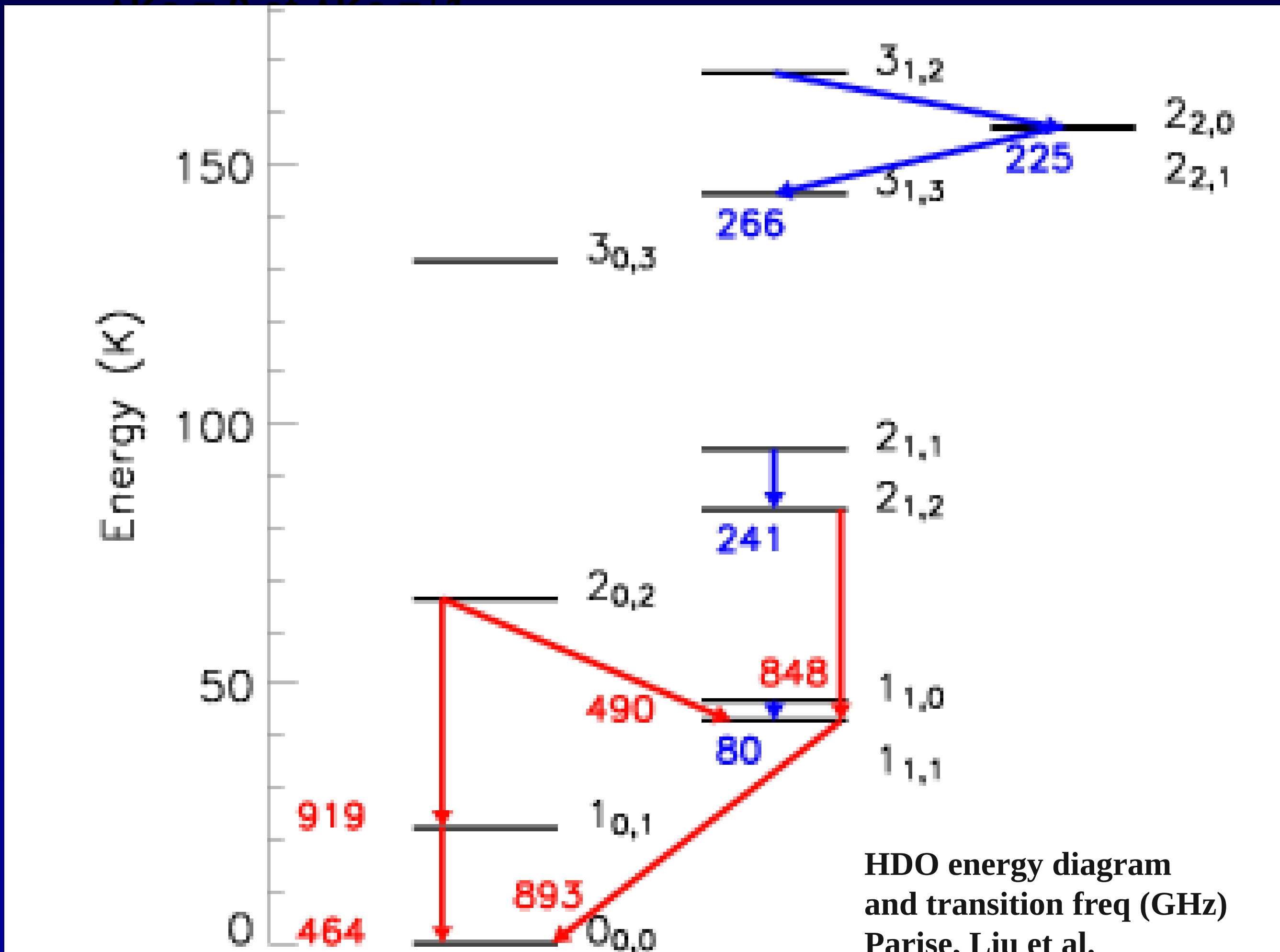

Warm HDO/$H_2O$=3-6×$10^{-4}$

241 GHz 225 GHz 143 GHz 255 GHz



# HDO spectrum

**HDO : Toupie assymétrique**




**HDO energy diagram and transition freq (GHz) Parise, Liu et al.**

# High-mass YSOs

Astron. Astrophys. 314, 281–294 (1996)

ASTRONOMY AND ASTROPHYSICS

**Warm HDO/$H_2O$~$3\times10^{-4}$**

## Water in galactic Hot Cores

P.D. Gensheimer[1], R. Mauersberger[1,2,3], and T.L. Wilson[1]

Astron. Astrophys. 313, 657–663 (1996)

ASTRONOMY AND ASTROPHYSICS

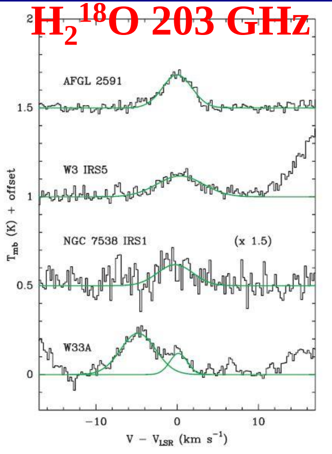
**$2\text{-}6\times10^{-4}$**

## The excitation and abundance of HDO toward W 3(OH)/($H_2O$)

F.P. Helmich[1,2], E.F. van Dishoeck[1,3], and D.J. Jansen[1]

**Include 464 GHz line**

**$H_2{}^{18}O$ 203 GHz**




A&A 447, 1011–1025 (2006)
DOI: 10.1051/0004-6361:20053937


Astronomy & Astrophysics

**~$10^{-3}$**

## Water in the envelopes and disks around young high-mass stars

F. F. S. van der Tak[1], C. M. Walmsley[2], F. Herpin[3], and C. Ceccarelli[4]

# HDO/$H_2O$ ice limits

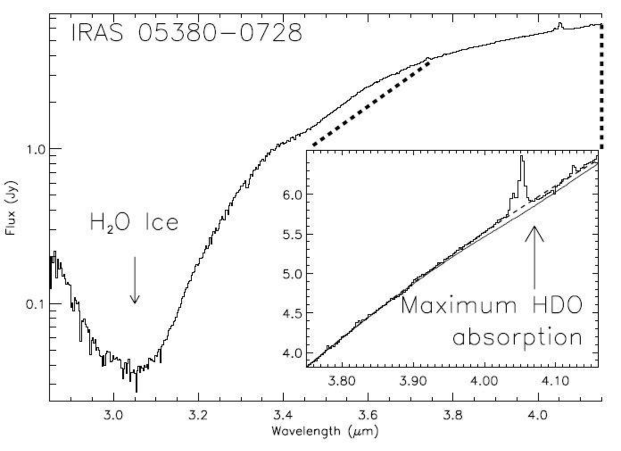
A&A 399, 1009–1020 (2003)
DOI: 10.1051/0004-6361:20021558


Astronomy & Astrophysics

**Solid HDO/$H_2O$<0.002-0.01**

## Revisiting the solid HDO/$H_2O$ abundances*

E. Dartois[1], W.-F. Thi[2,3], T. R. Geballe[4], D. Deboffle[1], L. d'Hendecourt[1], and E. van Dishoeck[3]




A&A 410, 897–904 (2003)
DOI: 10.1051/0004-6361:20031277

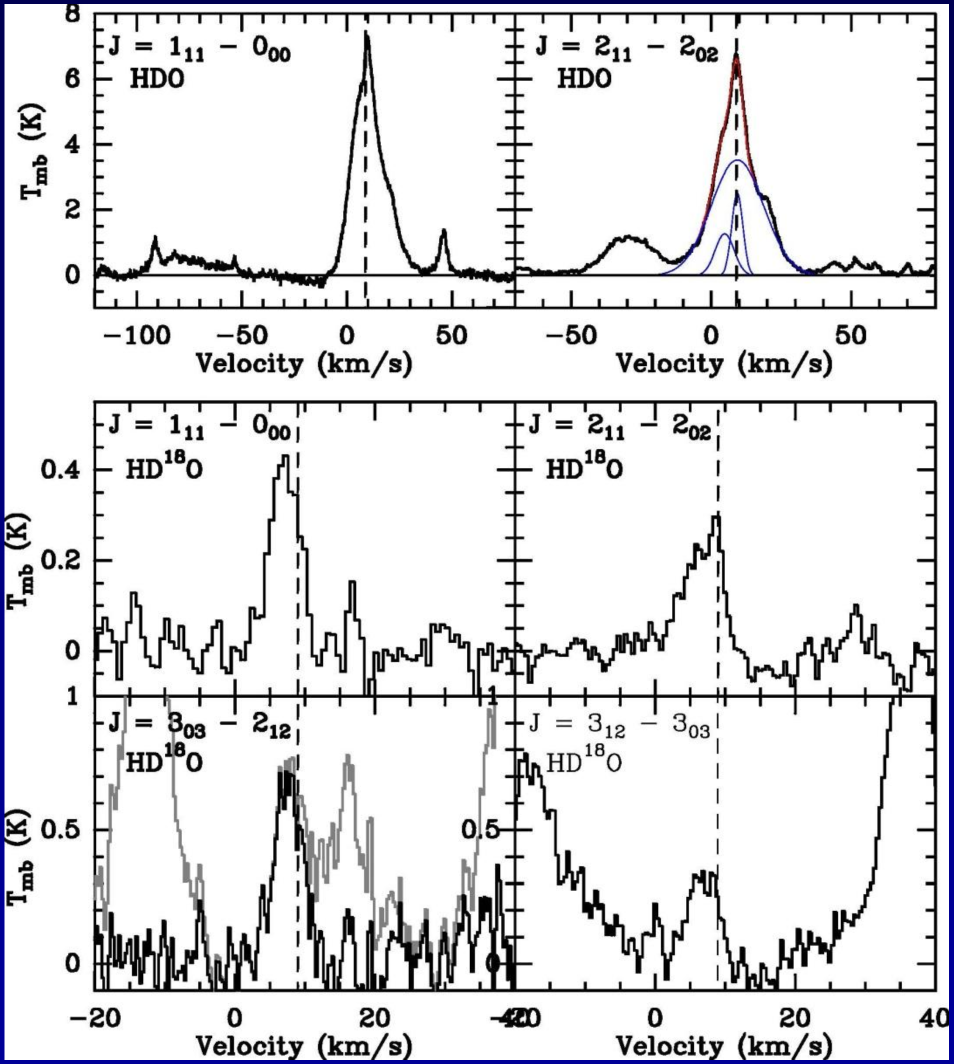

Astronomy & Astrophysics

**Solid HDO/$H_2O$<0.005-0.02**

## Search for solid HDO in low-mass protostars

B. Parise[1], T. Simon[2], E. Caux[1], E. Dartois[3], C. Ceccarelli[4], J. Rayner[2], and A. G. G. M. Tielens[5]

# Detection $HD^{18}O$ in Orion




**Use $HD^{18}O$ to better constrain HDO in Orion**

## $\Rightarrow HDO/H_2O = 0.01$

**Consistent with Persson et al. 2007, but higher than previous estimates**

**Bergin et al. 2010**

***See updated ratio in presentation Darek Lis***

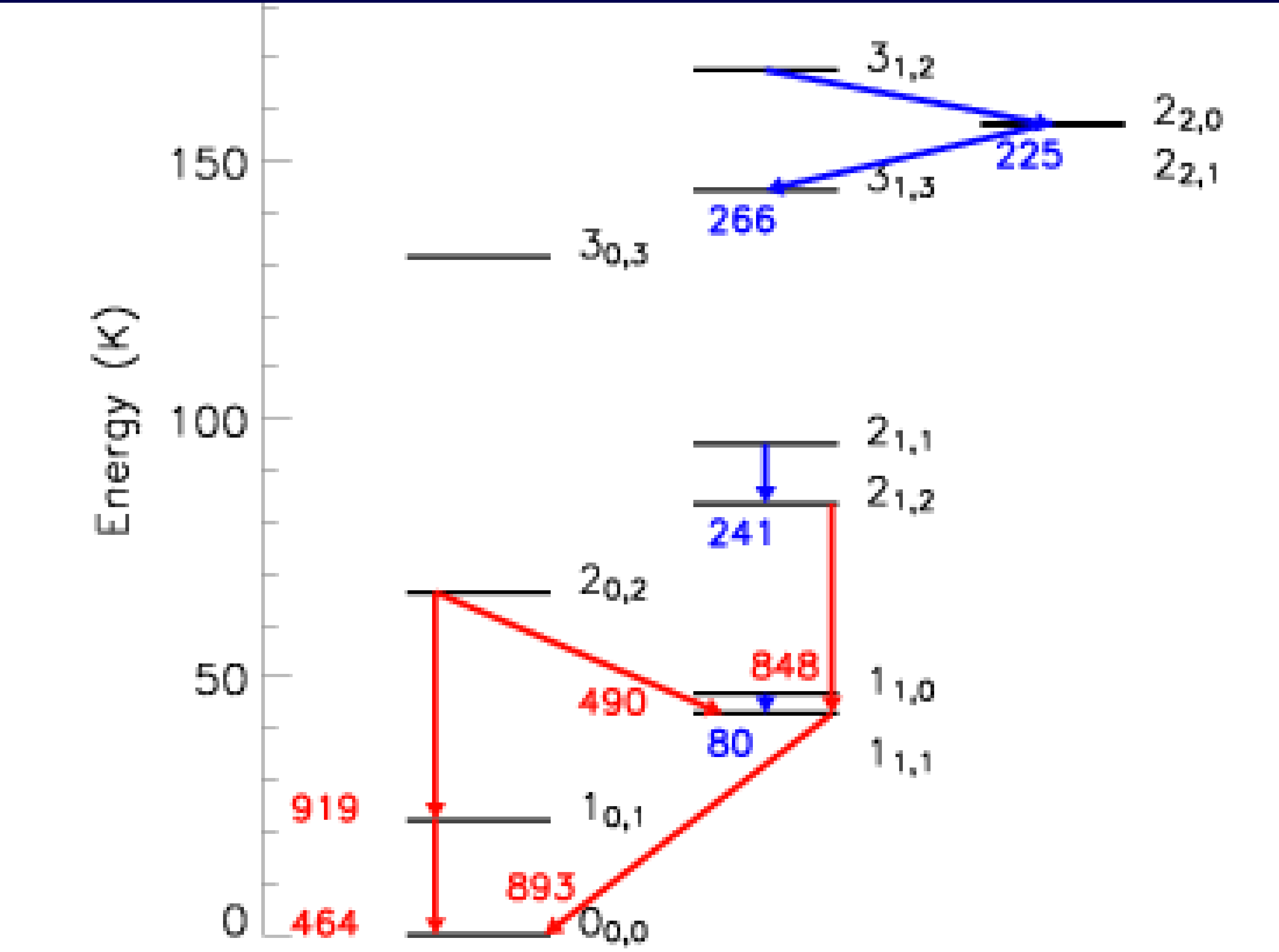
# Puzzling HDO/$H_2O$ ratios

- **High-mass hot cores: 0.01 vs. <0.001?**
- **Low mass protostars:**
  - **IRAS 16293 -2422: 0.03 (warm), 0.005 (cold)**
    - **Coutens et al. 2012**
    - **Need for photodesorption layer**
  - **NGC 1333 IRAS2A: >0.01 (warm), 0.01-0.1 (cold)**
    - **Liu et al. 2011**
    - **Persson et al. in prep find more than factor 50 lower value for warm HDO from interferometry data**
  - **NGC 1333 IRAS4B: <0.0006 (warm)**
    - **Jørgensen et al. 2010**

***Problem is determining $H_2O$ rather than HDO***

**see also Comito et al. 2010 for SgrB2(M)**

# HDO HIFI program: focus on 893 GHz line




- HDO 893 GHz line important for constraining cold $HDO/H_2O$
- Combine with ground-based HDO data for warm $HDO/H_2O$

# HDO/$H_2O$ example spectra HIFI

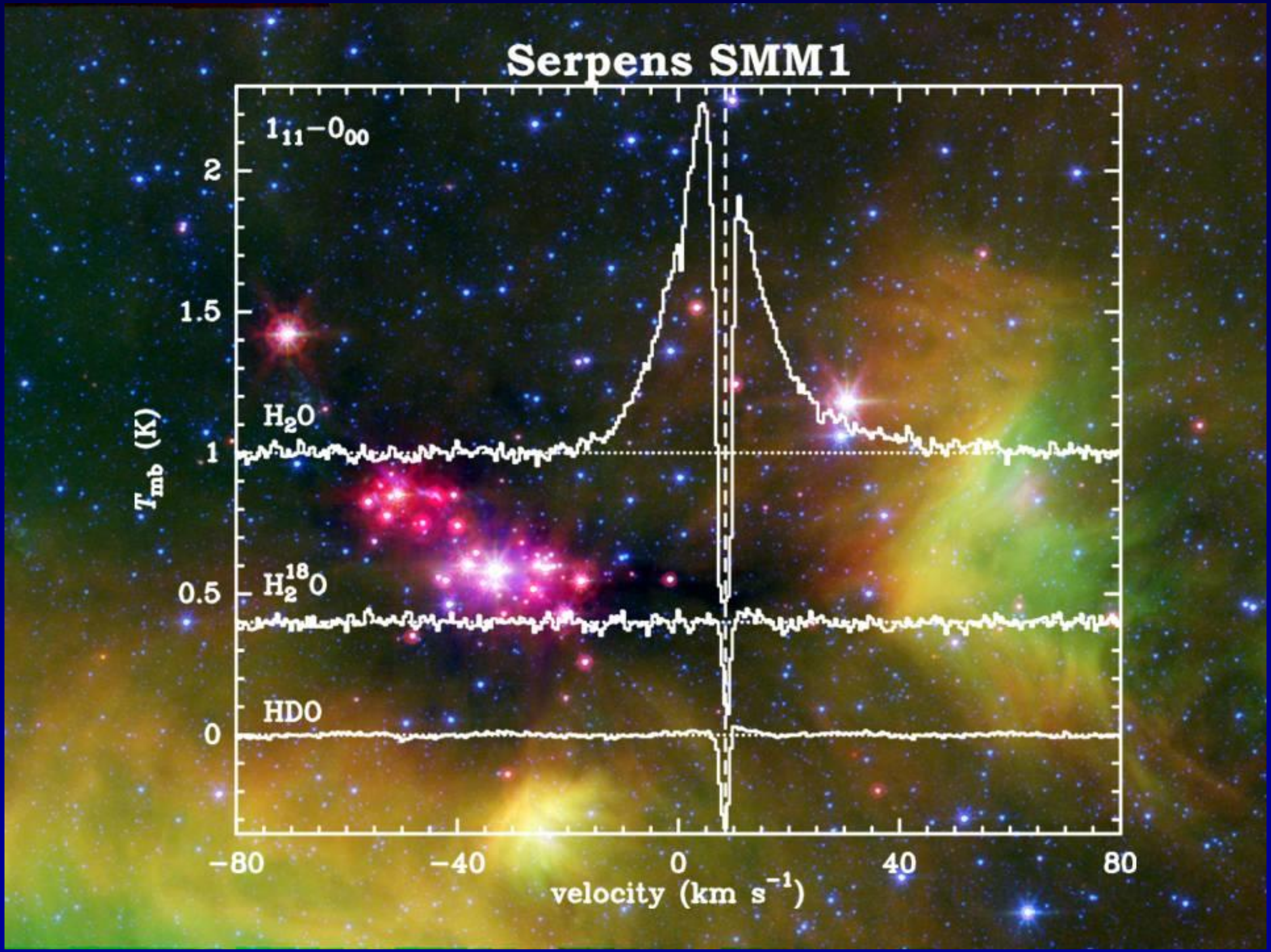



Fig. by Visser

Mottram, Schmalzl et al.

Coutens et al.

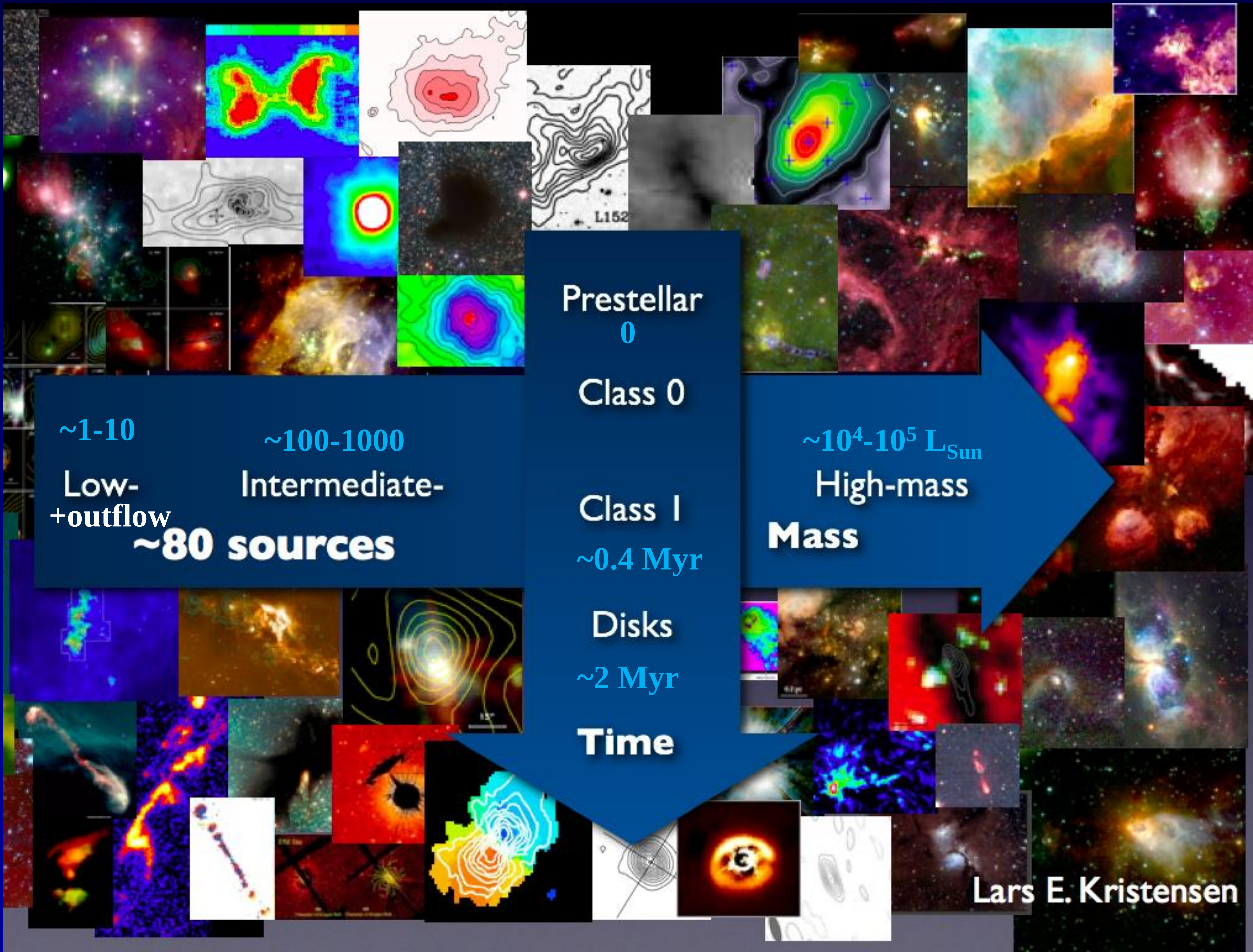
**Constraining the cold and warm HDO/$H_2O$ ratios**

# Some recent WISH results on $H_2O$

RCW120
A. Zavagno

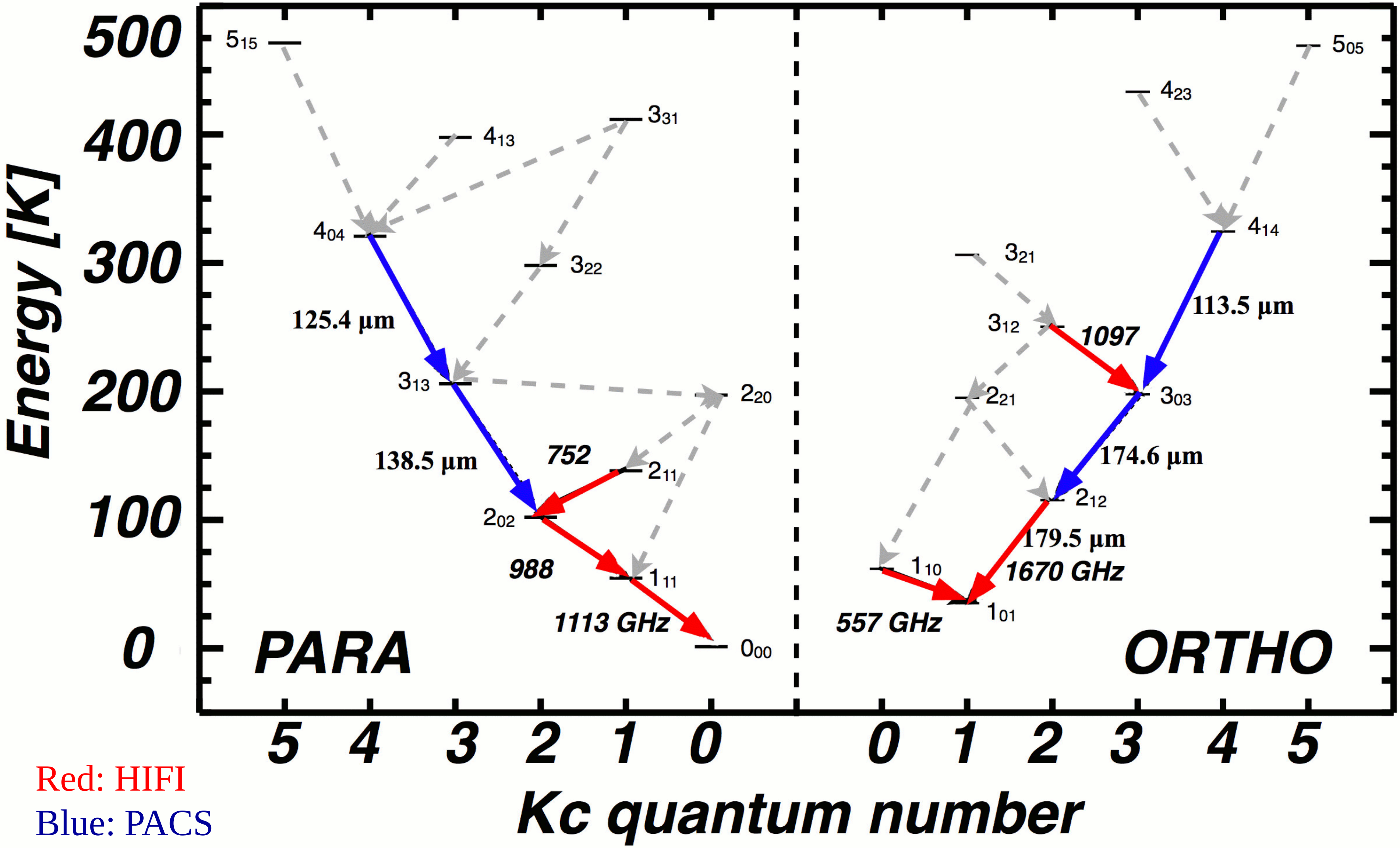
*Ewine F. van Dishoeck*
*Leiden Observatory/MPE*

*www.strw.leidenuniv.nl/WISH*



Prestellar
0
Class 0
Class I
~0.4 Myr
Disks
~2 Myr
Time
~1-10
Low-
+outflow
~100-1000
Intermediate-
~80 sources
~$10^4$-$10^5$ $L_{Sun}$
High-mass
Mass
Lars E. Kristensen

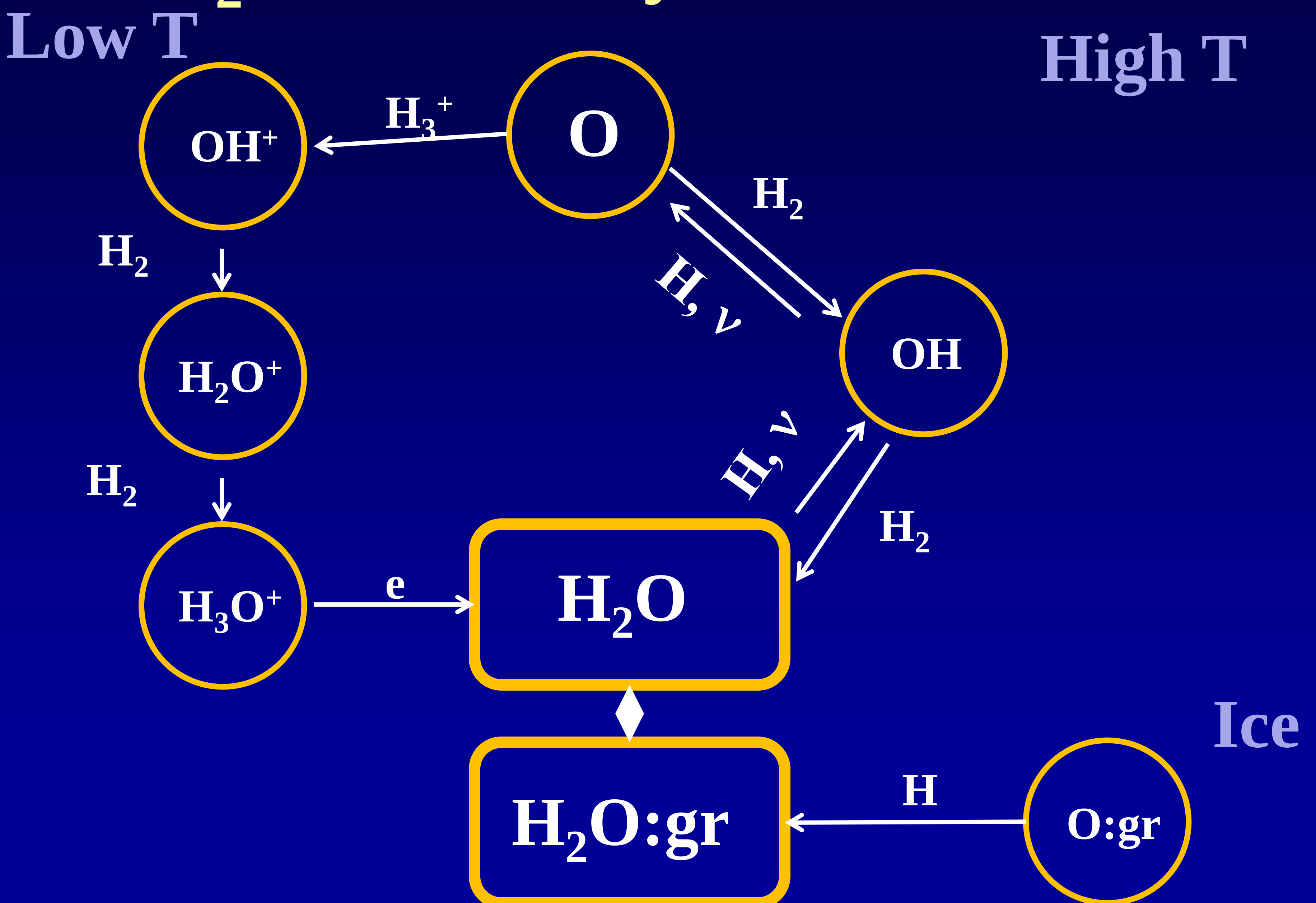
# $H_2O$ lines: HIFI and PACS



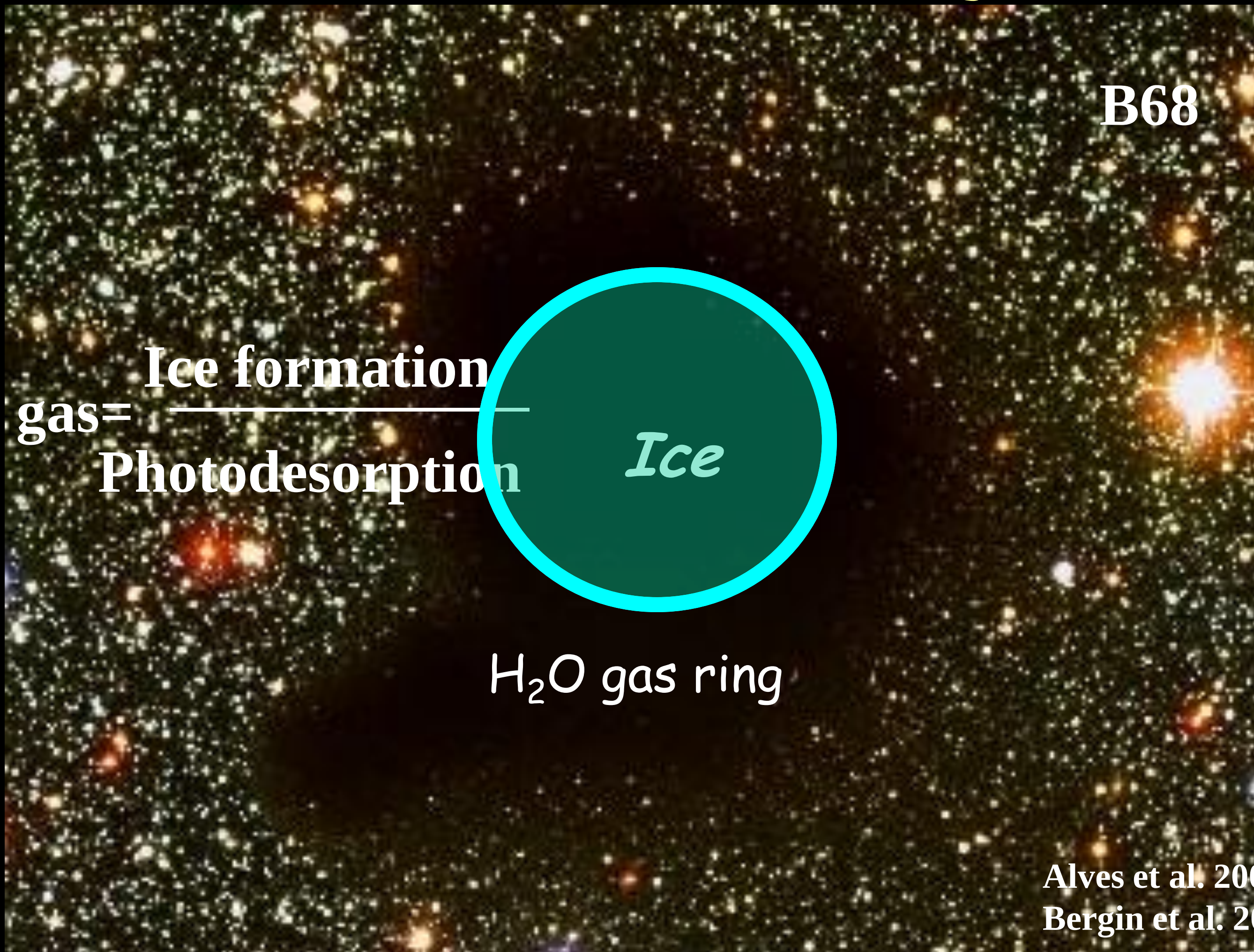

Red: HIFI
Blue: PACS

**Observe mix of low- and high-excitation lines to probe cold and hot environments; Include $^{12}CO$ 10-9, $^{13}CO$ 10-9, $C^{18}O$ 9-8, PACS**

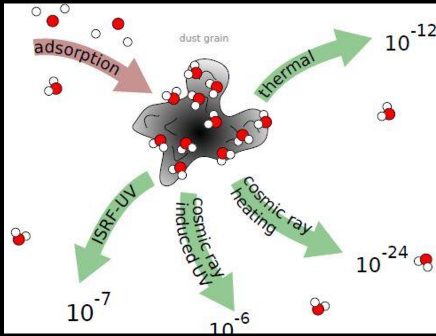
# $H_2O$ chemistry: three routes

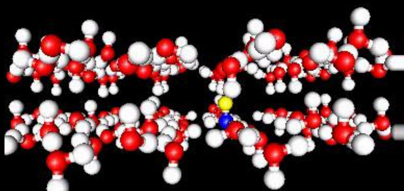


# Importance of gas-grain chemistry




$$H_2O\ \text{gas} = \frac{\text{Ice formation}}{\text{Photodesorption}}$$



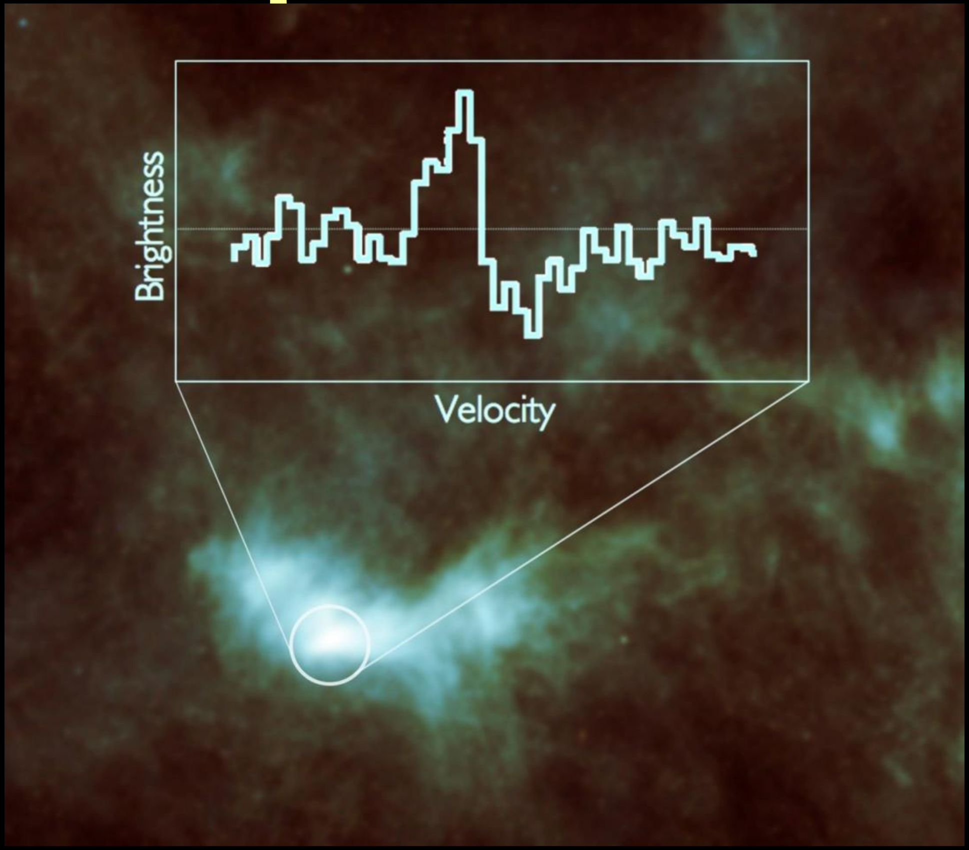
Lab + Theory

A&vD2008
Öberg et al. 2009

**$n$=2.10$^4$ – 5.10$^6$ cm$^{-3}$, $T$=10 K**

**Layer of water gas where ice is photodesorbed**

# Detection of cold water reservoir in pre-stellar cores

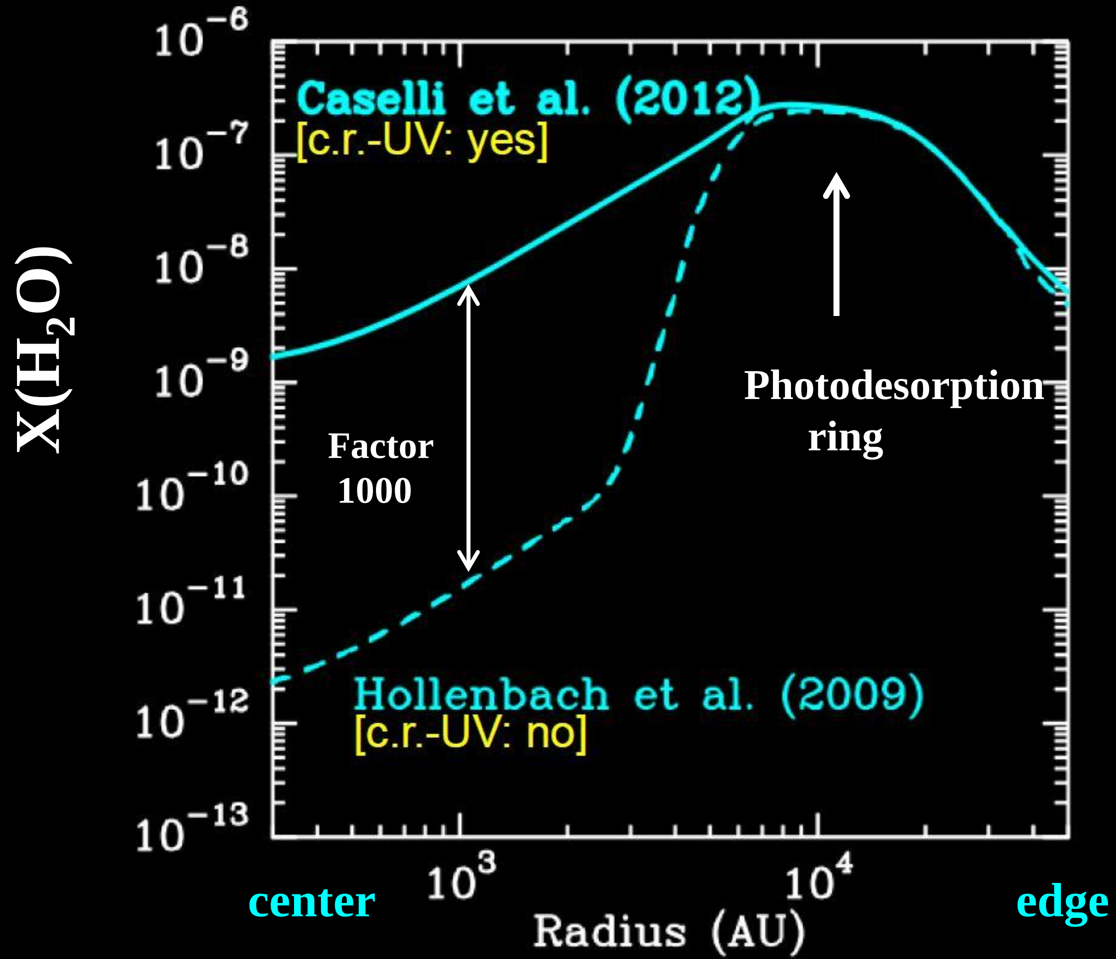



ESA Sci-Tech Note

- Simple ice chemistry works
- High density required for emission

Caselli et al. 2012

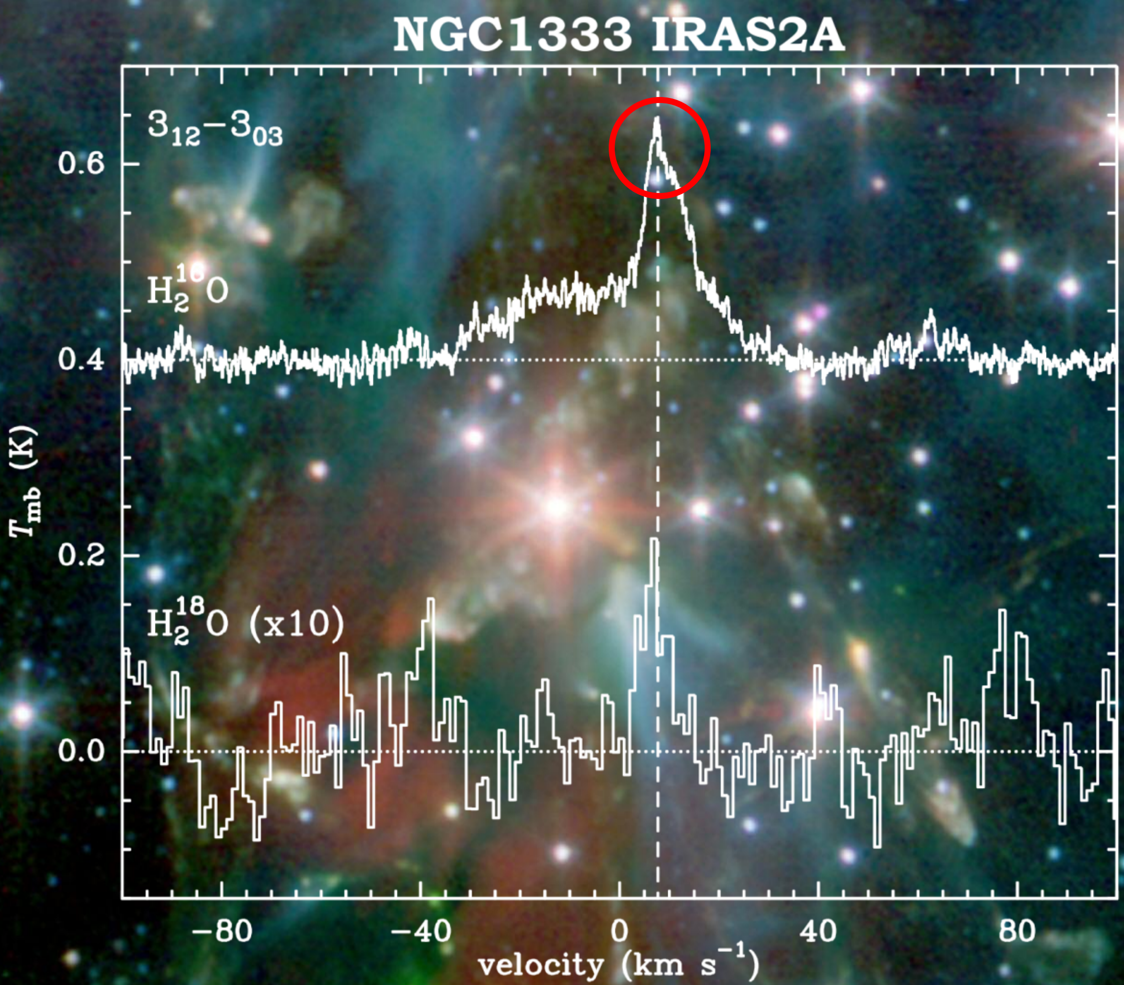
# Inferred water abundance L1544




-Need efficient photodesorption in center by CR induced photons

-Also applies to outer envelope protostars (Schmalzl, Mottram et al. in prep.)

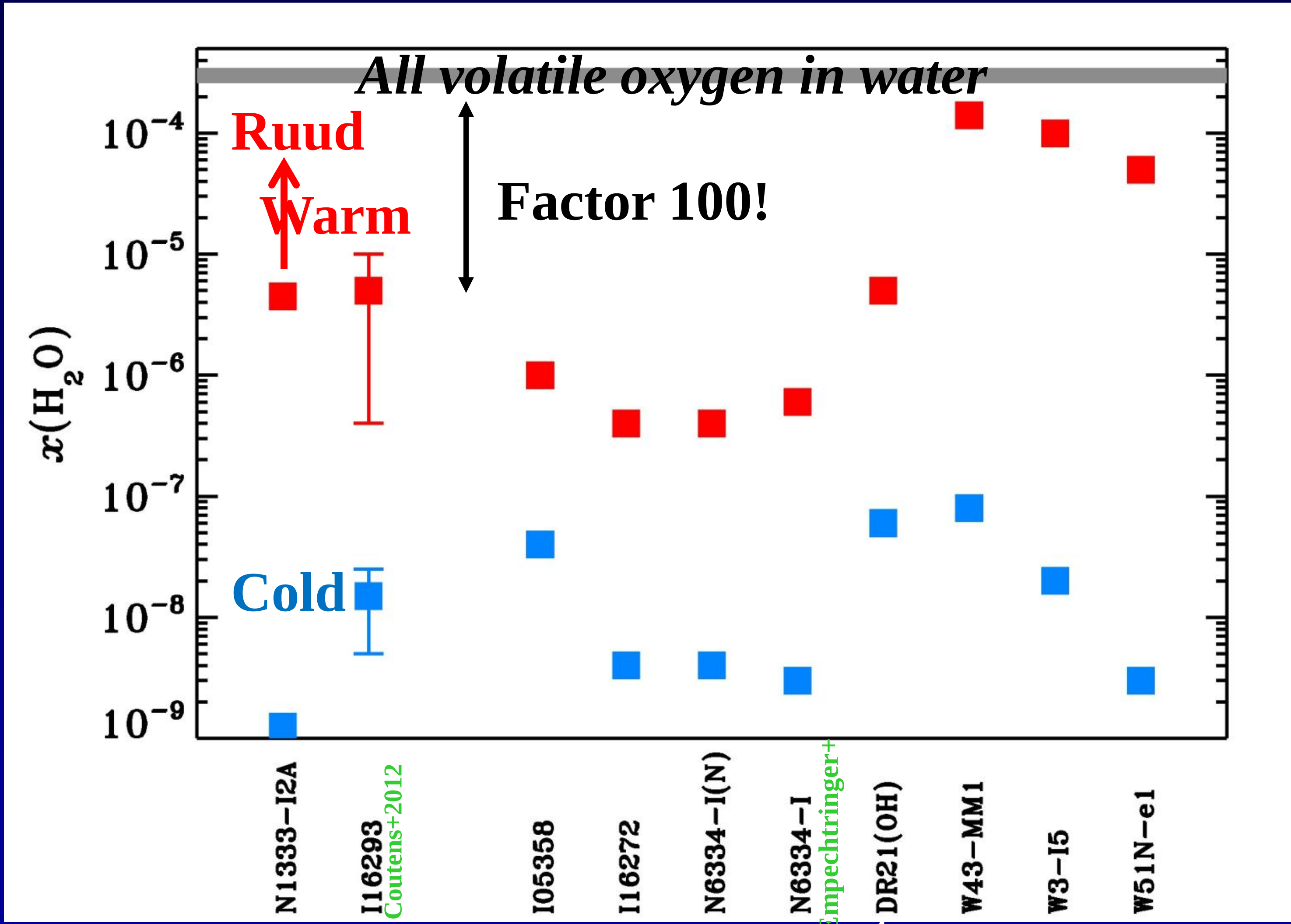
# Hot cores: wet or dry?




Visser et al.
In prep

- Deep 5 hr integration on excited line reveals narrow $H_2^{18}O$ and also shows narrow $H_2^{16}O$ component
- Abundance ~few $\times 10^{-5}$ to $10^{-4}$, higher than thought before

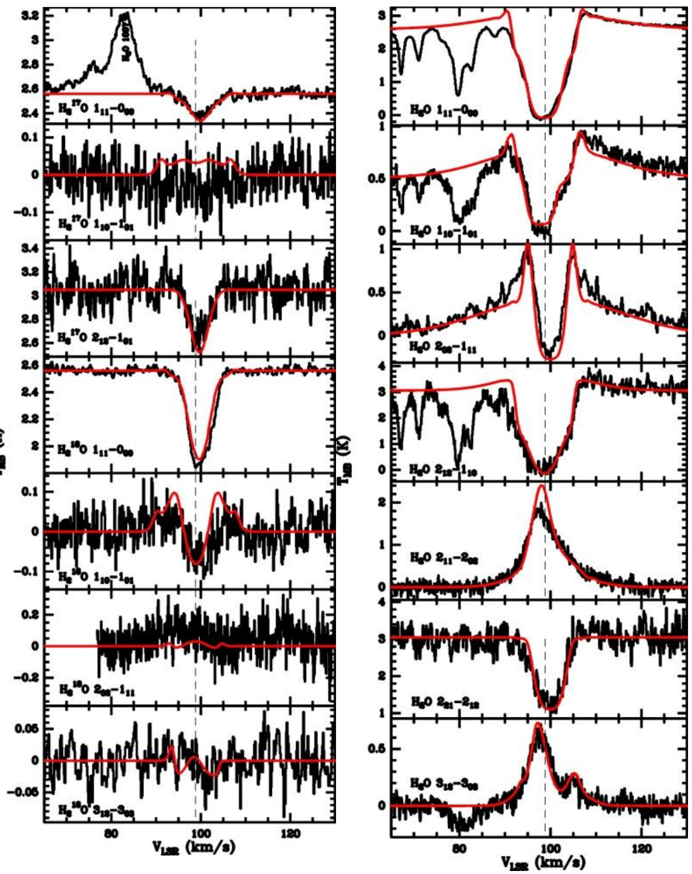
# High temperature chemistry: How ‘wet’ are hot cores?




- Why is warm abundance not > $10^{-4}$?
- What causes variations from source to source? Physics?

# Hot core chemistry W43MM1

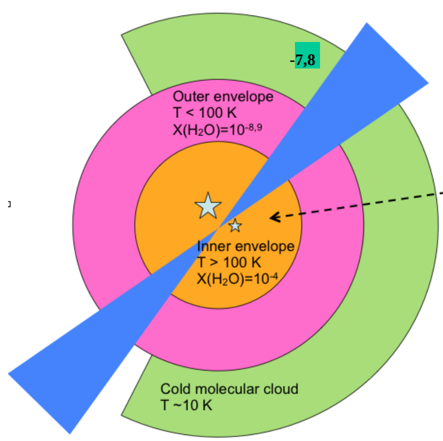
**Isotopes** **$H_2{}^{16}O$**




Herpin et al. 2012

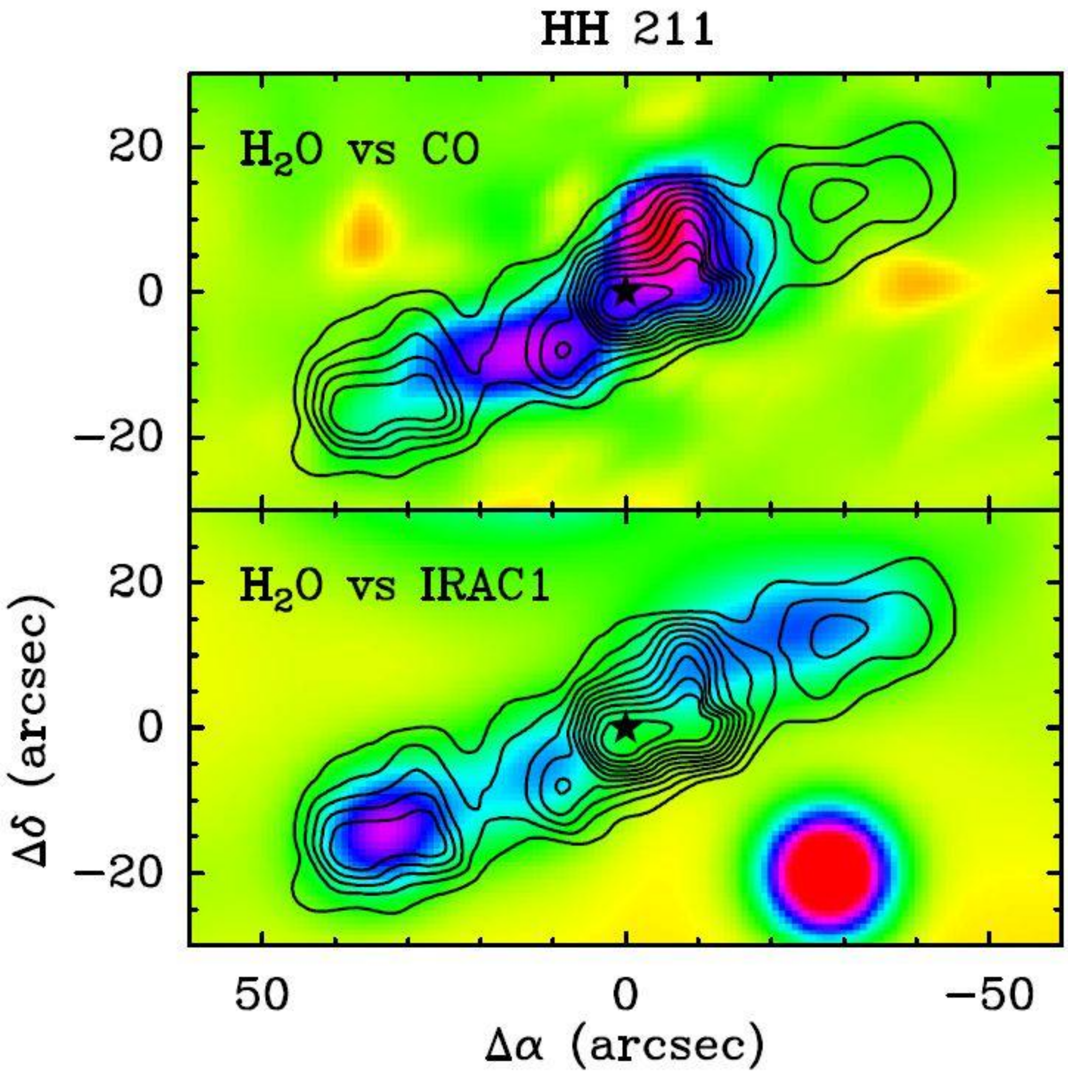
$L=2.10^4\ L_{sun}$
D=5.5 kpc

| Parameter | |
|---|---|
| $X_{H_2O}$ | 8.0 (±1.0) ×10$^{-8}$ |
| Post-jump $X_{H_2O}$ | 1.4 (±0.4) ×10$^{-4}$ |
| o/p | 3 ±0.2 |
| $X_{^{18}O/^{17}O}$ | 4.5 |
| $X_{^{16}O/^{18}O}$ | 450 |
| $V_{tur}$ (km s$^{-1}$) | 2.2-3.5 |
| $V_{outflow}$ (km s$^{-1}$) | 10.2-35.5 |
| $V_{infall,max}$ (km s$^{-1}$) | -2.9 |
| $V_{LSR}$ (km s$^{-1}$) | 99.4 |




**Inner water abundance consistent with $10^{-4}$**

# Water in outflows




**Tafalla et al.**
**In press**

**Nisini et al. 2013**

**Santangelo et al.**
**in prep.**

- **$H_2O$ and high-J CO, $H_2$ go together**
- **$H_2O$ abundance low, $10^{-7} – 10^{-5}$**

# Summary

# Preliminary numbers (subject to change)

| Source | Cold | Warm | Ref | PDlayer |
|---|---|---|---|---|
| Orion | | 0..002-0.005 | Neill et al. | |
| NGC 6334 | | 0.0002 | Emprechtinger eta | |
| W33A | | ~0.001 | vdTak et al. | |
| G327.3 | | | | |
| NGC7129 | | | | |
| NGC2071 | | | | |
| L1157 | | 0.001 | Codella et al. | |
| IRAS16293 | 0.005 | 0.034 | Coutens et al. | 0.05 |
| | | 0.0009 | Persson et al. | |
| N1333 I2A | <0.025 | >0.01 | Liu et al. | |
| | | | | |
| N1333I4A | | | | |
| | | ~0.001 | Persson et al. | |
| N1333I4B | | <0.0006, ~0.001 | J,&vD, Persson et al. | |

**Need to reconcile differences, especially for low-mass sources**

# Isotope selective processes

- D/H in the gas enhancing $HDO/H_2O$ in the grains
  - o/p $H_2$ ratio => $H_2D^+$ ↑ => D ↑
  - CO freeze out => $H_2D^+$ ↑ => D ↑
- Gas phase fractionation starting with $H_2D+$
  - CO freeze-out
- Isotope selective photodissociation? Unlikely
- Isotope selective photodesorption? Quantified, small effect (Arasa et al. in prep)
- High $T$ D + OH → H + OD

# Grain surface processes

- Thermal exchange reactions: H/D exchange
  - $H_2O$ + $D_2O$, $H_2O$ + OD at high ice T
- OH + $H_2$ vs slower OD + $H_2$ tunneling
- .....
- O + $H_2$ does not go

# Papers

- Coutens et al.: IRAS4A, 4B, few months
- Liu et al. IRAS2A, high mass: TBC
- Persson et al. I4A,4B,2A PdbI few months
- Joe, Markus: $H_2O$ modeling: few months
- Yunhee: get 464 GHz, 225/241 GHz data ~yr
- Floris, Charlotte: W33A
- Fuente: IM sources (NGC 2071, 7129)
- vD+ synthesis paper ~2014
  - See also PPVI chapters CC+, vD+