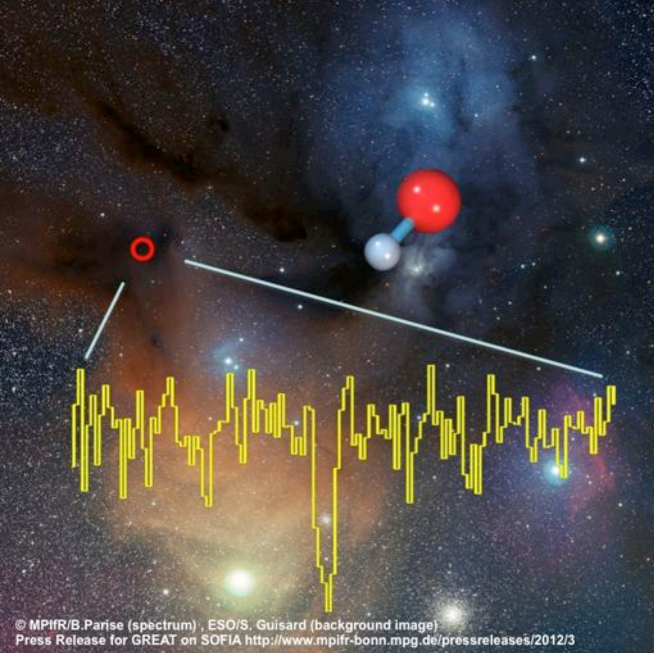


# Detection of OD with SOFIA

SOFIA Community Tele-Talk,
December 2013


**Dr. Bérengère Parise**
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**MPIfR, Bonn, Germany**
in collaboration with F. Du, F.C. Liu, A. Belloche, R. Güsten, K. Menten and the SOFIA/GREAT team

# Water formation in the ISM?

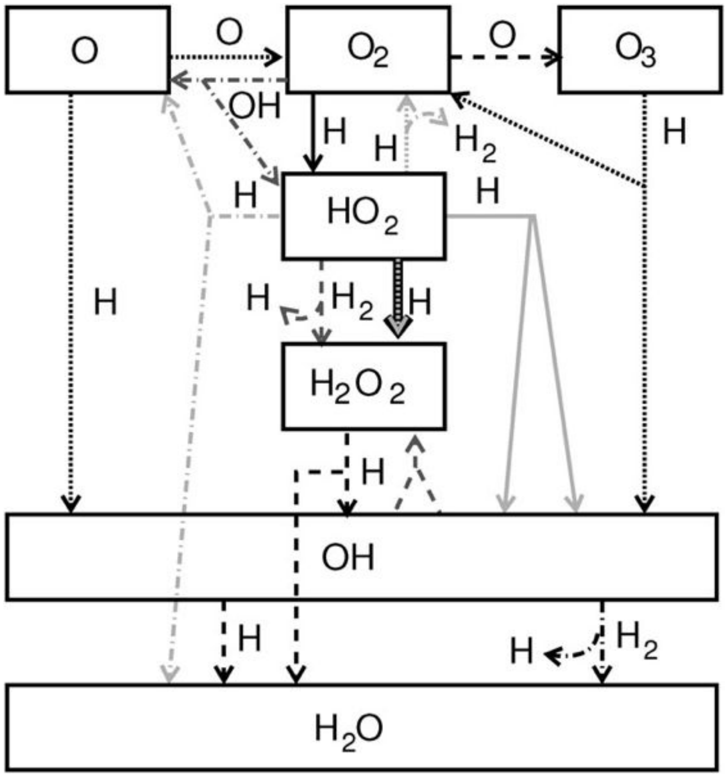
Water formation in cold gas:

$O + H_3^+ \rightarrow OH^+$
$O^+ + H_2 \rightarrow OH^+$
$OH^+ + H_2 \rightarrow H_2O^+$
$H_2O^+ + H_2 \rightarrow H_3O^+$
$H_3O^+ + e^- \rightarrow H_2O$

Water formation in hot gas:

$OH + H_2 \rightarrow H_2O + H$

Water formation on dust surfaces:




Cuppen et al. 2010

# Water formation constrained in one particular environment

Hair bleach is found in deep space

By Paul Sutherland on July 6, 2011 2:19 pm / no comments

Astronomers have for the first t... hair bleach in the depths of space and say it gives them a clue to where wa... universe.

Molecules of hydrogen peroxi... discovered in clouds of cosm... dust where new stars are b... light years from Earth.

The chemical is familia... use as a disinfectant ... blonde. But scientist... find because its for... to oxygen and wa... ingredients for lif...

The interstella... star Rho in th... the serpent... astronome... Experim... mounta...

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A nebula to dye for!

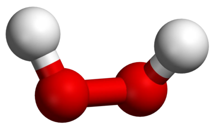
Jonathan Nally | Jul 06, 2011 | Comments 0

The colourful Rho Ophiuchi star formation region, about 400 light-years from Earth, contains very cold (around -250 degrees Celsius), dense clouds of cosmic gas and dust, in which new stars are being born. Astronomers using the APEX telescope have detected hydrogen peroxide molecules in the area marked with the red circle.

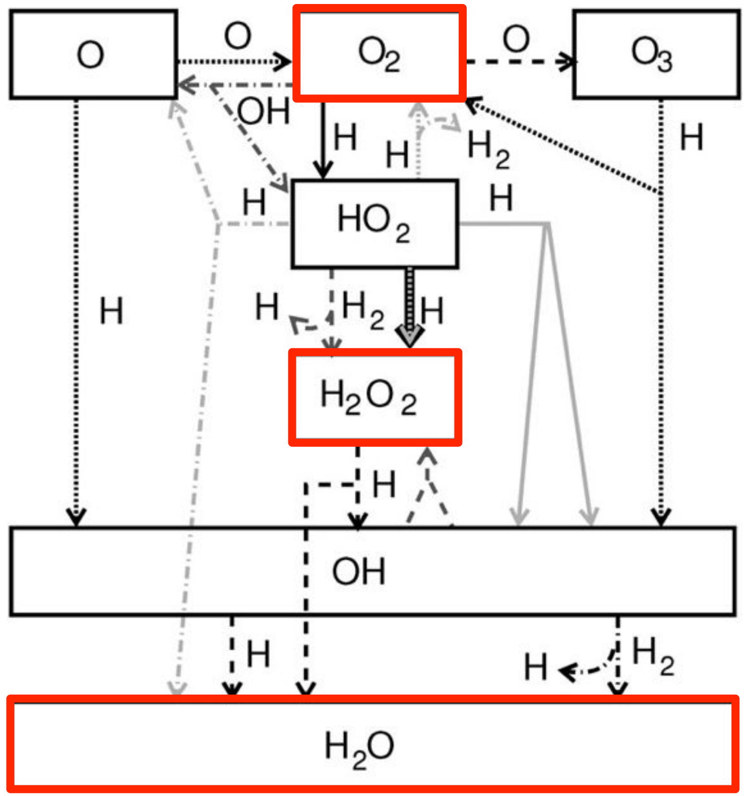
**MOLECULES OF HYDROGEN PEROXIDE** have been found for the first time in interstellar space. The discovery gives clues about the chemical link between two molecules critical for life: water and oxygen.

First detection of $H_2O_2$ in the interstellar medium with the APEX telescope, towards Oph A

**(Bergman, Parise, Liseau et al. 2011)**



# Water formation constrained in one particular environment




Grain surface chemistry formation of water
(Cuppen et al. 2010)

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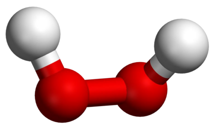
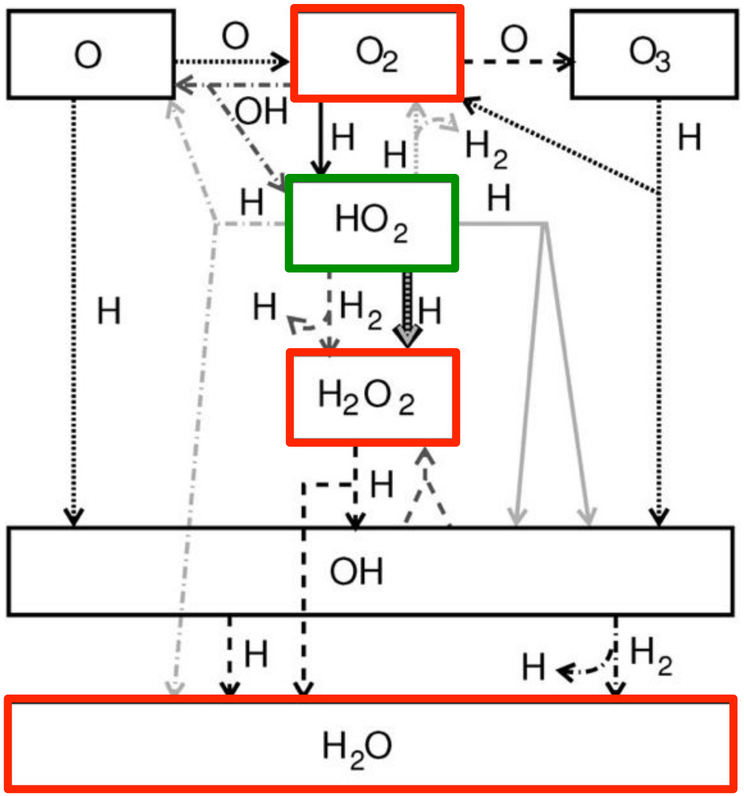


Relevance to the chemistry of water.

# Water formation constrained in one particular environment

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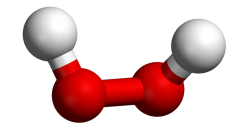
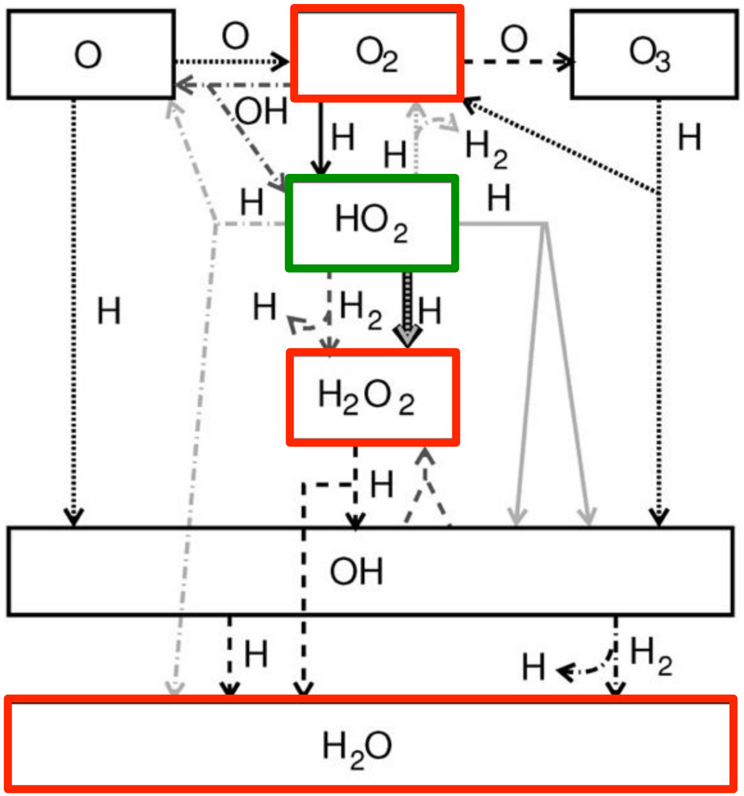


Relevance to the chemistry of water.

Astrochemical modeling of the abundance of $H_2O_2$, $O_2$, and other molecules predicted the abundance and detectability of a new molecule: $HO_2$
**(Du, Parise & Bergman, 2012)**

# Water formation constrained in one particular environment

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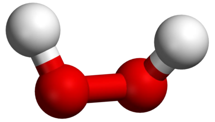

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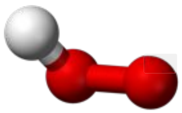
Astrochemical modeling of the abundance of $H_2O_2$, $O_2$, and other molecules predicted the abundance and detectability of a new molecule: $HO_2$
**(Du, Parise & Bergman, 2012)**

First detection of $HO_2$ with the APEX and IRAM telescopes and validation of the prediction of the astrochemical model
**(Parise, Bergman & Du 2012)**



**In this environment (~20K), the $O_2$ route to water is dominant**

# Follow-up search for $H_2O_2$ towards a sample of sources

*Parise et al., Faraday Discussion 168, subm.*

- Using the APEX telescope, search for $H_2O_2$ towards a sample of 10 sources, including low-mass protostars, IRDCs, massive YSOs, …
- No detection obtained, with upper limits on $H_2O_2$ abundance (much) lower than abundance in Oph A
- Similarity with the $O_2$ search
- Oph A seems to be a unique example of a source where conditions are about right (~ 20-30 K) for the $O_2$ route to be dominant in the formation of water. This particularity may result from external heating by the “S1” source.
- The abundance of $H_2O_2$ may thus be used to constrain the physical conditions during the source evolution.


**7 - 9 April 2014, Leiden, The Netherlands**
**Call for poster abstracts - deadline 27 January 2014**

# Other approach to constrain water formation: isotopic study

**Measuring the deuterium fractionation of water**

**Liu et al. 2011**

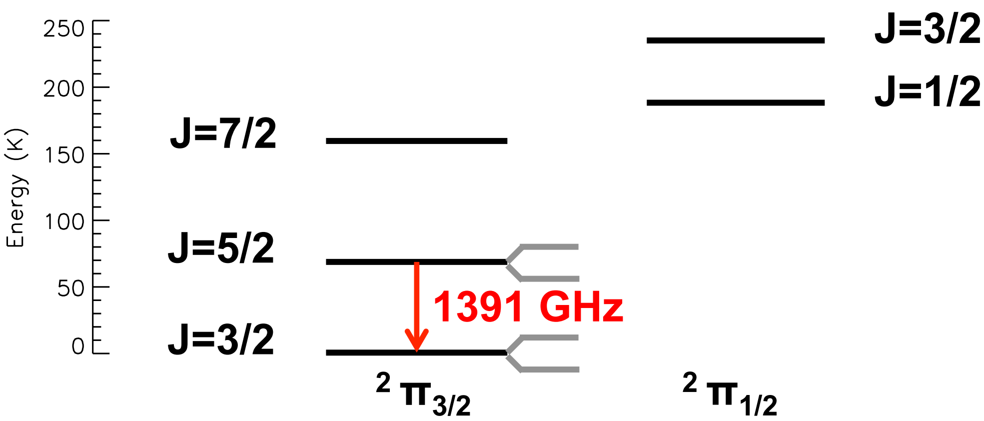
| Source | $\frac{HDO}{H_2O}$ | | $\frac{HDCO}{H_2CO}$ [b] | $\frac{CH_2DOH}{CH_3OH}$ [b] |
|---|---|---|---|---|
| | Inner | outer ($3\sigma$) | – | – |
| IRAS2A[a] | $\geq 0.01$[c] | $0.07^{+0.11}_{-0.06}$[c] | $0.17^{+0.12}_{-0.08}$ | $0.62^{+0.71}_{-0.33}$ |
| IRAS 16293[d] | 0.03 | $\leq 0.002$ | $0.15 \pm 0.07$ | $0.37^{+0.38}_{-0.19}$ |
| Orion KL | 0.02[e] | | 0.14[f] | 0.04[g] |

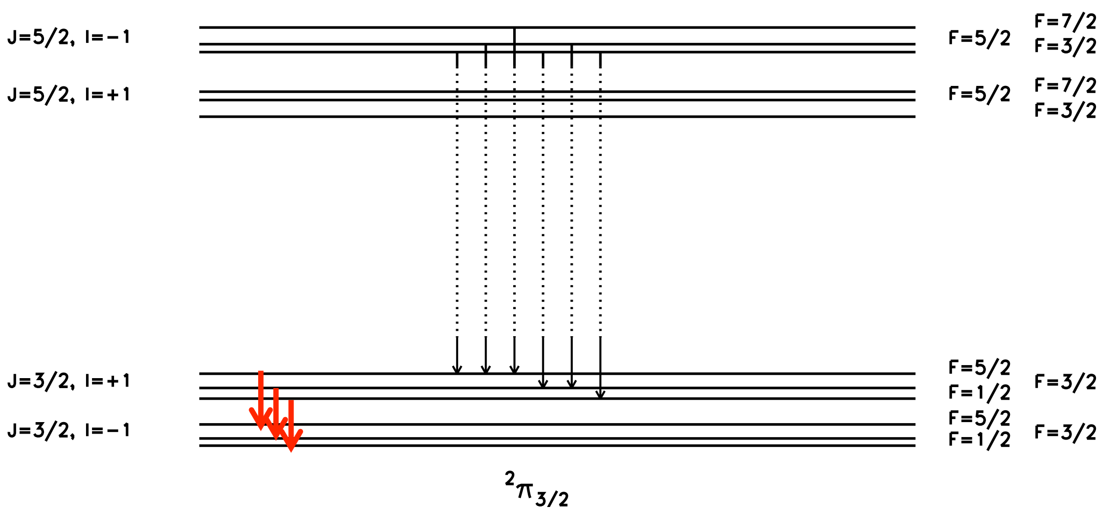
- **The deuterium content of water has been observed to be low compared to that of other molecules also formed on dust surfaces (e.g. $CH_3OH$) for over a decade now [e.g. Parise et al. 2005]**
- **The number of observational studies deriving $HDO/H_2O$ has been booming with the Herschel Space Observatory, and all confirm the lower deuterium fractionation of water [e.g. Liu et al. 2011, Coutens et al. 2013]**
- **The $HDO/H_2O$ directly measured in ices is also low (< 1%, Parise et al. 2003, Dartois et al. 2003)**

→ **Apparent problem for astrochemical models, but new generation of models propose different explanations (Cazaux et al. 2011, Taquet et al 2013, Du et al. in prep.)**

→ **Add more observational constraints: search for OD**

# Search for OD in the ISM



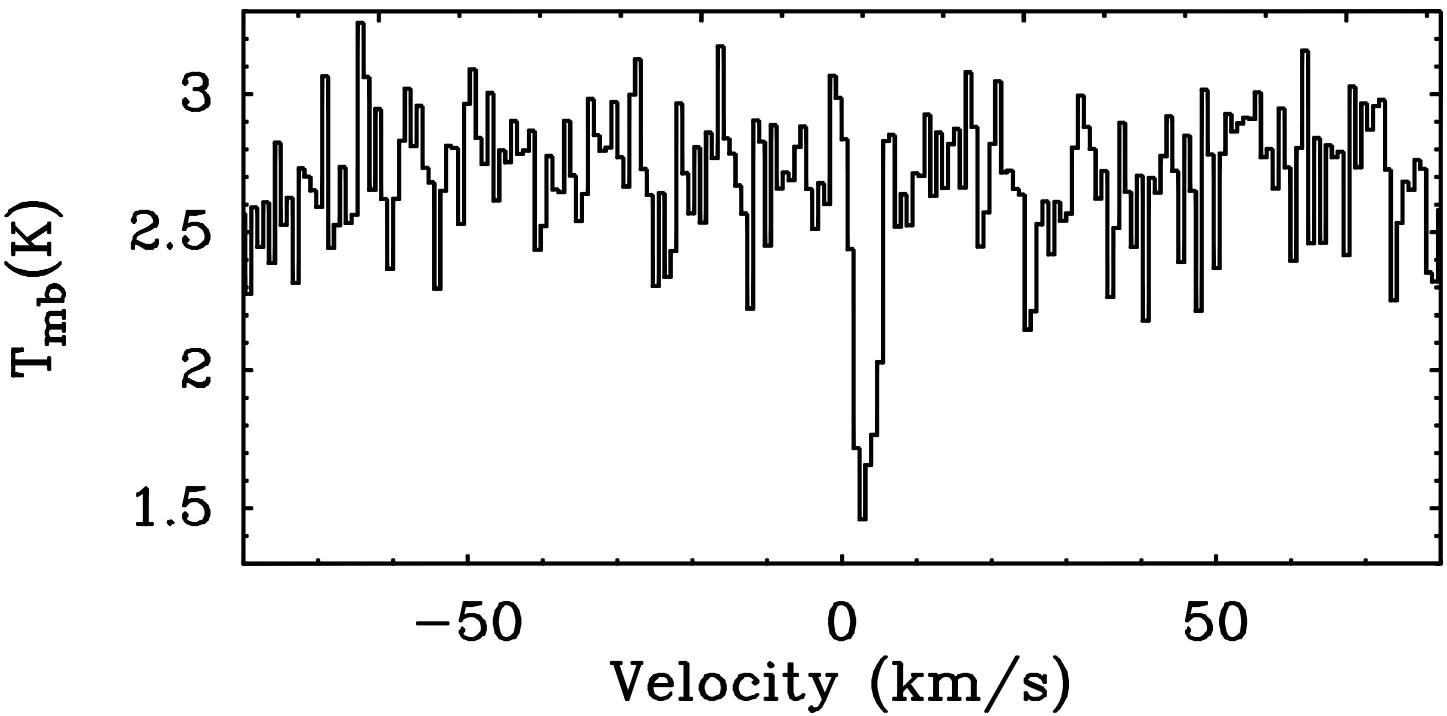

Previous attempts:

- Allen et al. 1974 at 310 MHz towards Galactic Center
- OD recently detected towards comet C/2002 T7 (LINEAR) via coaddition of 30 lines of UV fluorescence spectrum (Hutsemekers et al. 2008)
  OD/OH ~ 3.5 $10^{-4}$ , result of photo-dissociation of HDO and $H_2O$
- Our search: ground-state transition with SOFIA

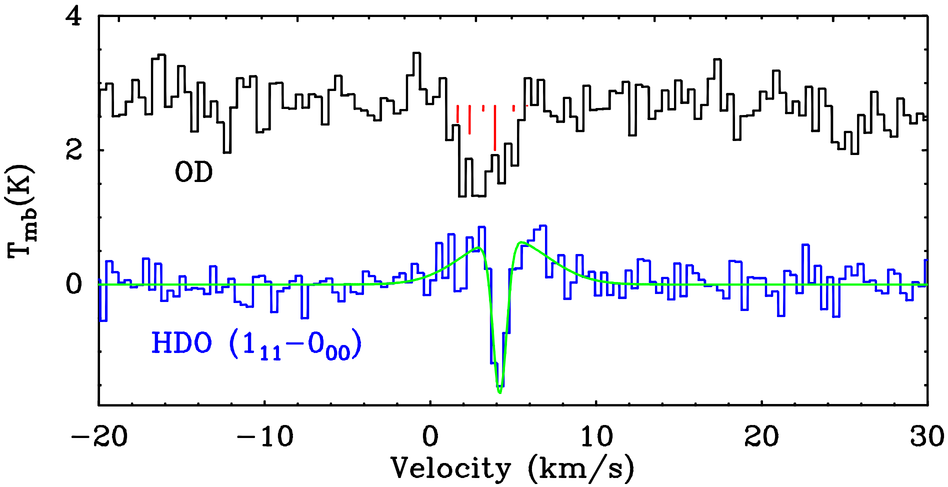
# Observation with SOFIA

Target: IRAS16293-2422, a low-mass protostar in the ρ Oph complex, where high levels of deuterium fractionation have been observed (up to the detection of $CD_3OH$, Parise et al. 2004)

OD ground state transition at 1391.5 GHz



# Column density of OD?

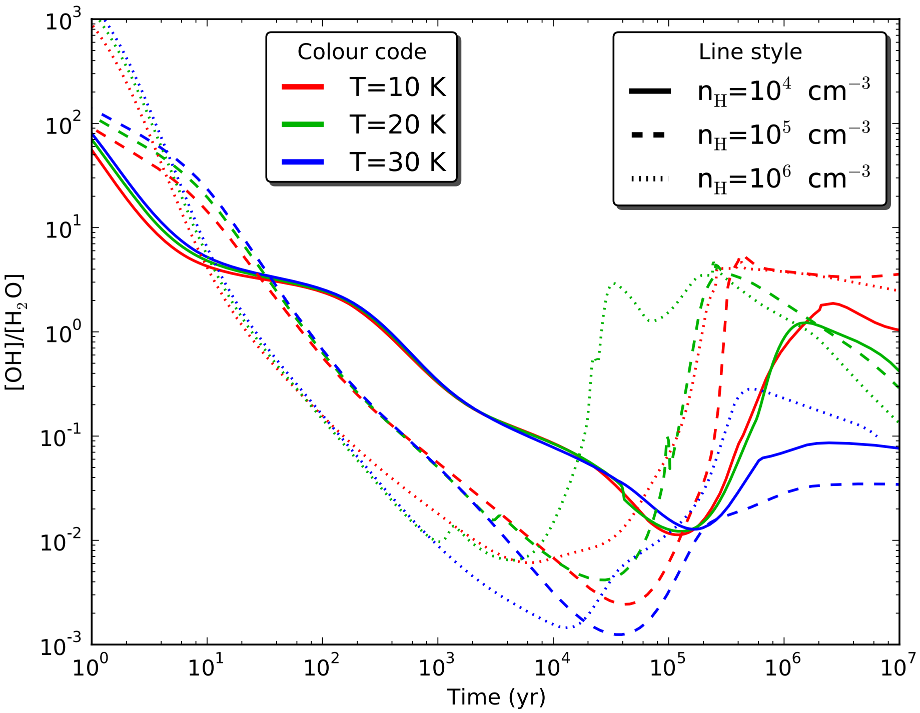


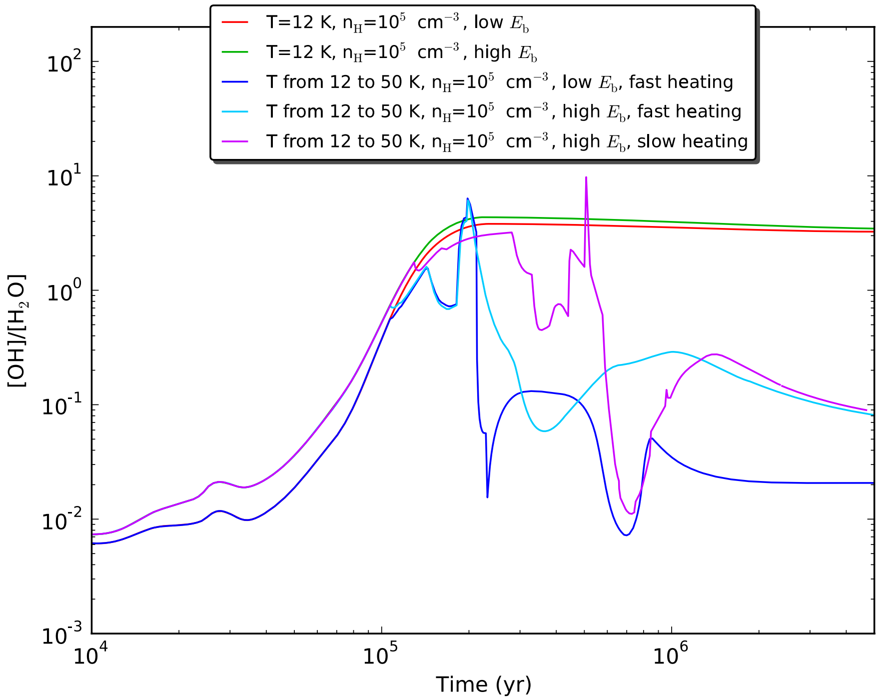

| Molecular line | Fit type | $\int T_{mb}\,dv$ (K km s$^{-1}$) | *FWHM* (km s$^{-1}$) | $v_{lsr}$ (km s$^{-1}$) |
|---|---|---|---|---|
| HDO $1_{1,1}-0_{0,0}$ | two-Gauss | $+4.4 \pm 0.6$ | $5.9 \pm 1.0$ | $4.5 \pm 0.3$ |
| | | $-2.4 \pm 0.3$ | $1.0 \pm 0.1$ | $4.2 \pm 0.1$ |
| OD 5/2→3/2, −1→+1 | one-Gauss | $-4.1 \pm 0.5$ | $2.9 \pm 0.3$ | – |
| OD 5/2→3/2, −1→+1 | hfs | – | $1.3 \pm 0.6$ | $4.2 \pm 0.2$ |

| $T_{ex}$ (K) | $N_{OD}$ (cm$^{-2}$) | $N_{HDO}$ (cm$^{-2}$) | OD/HDO |
|---|---|---|---|
| 2.7 | $(3.5 \pm 1.5) \times 10^{13}$ | $(6.0 \pm 1.5) \times 10^{11}$ | 60 ± 30 |
| 5.0 | $(5.0 \pm 2.0) \times 10^{13}$ | $(1.2 \pm 0.3) \times 10^{12}$ | 45 ± 20 |
| 10.0 | $(1.0 \pm 0.3) \times 10^{14}$ | $(4.0 \pm 1.0) \times 10^{12}$ | 27 ± 10 |

OD/HDO ~ 17 - 90

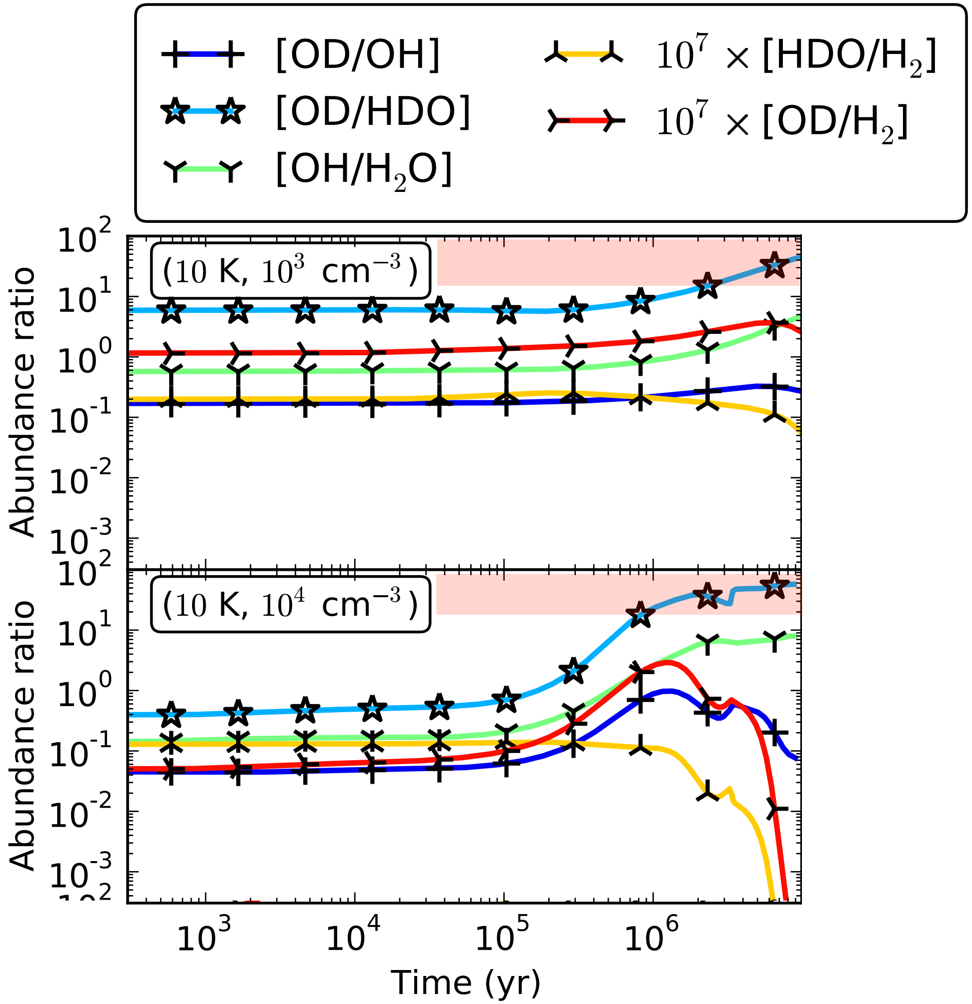
# Preliminary astrochemical modelling




OH/$H_2$O ratio predicted by the model from Du, Parise & Bergman (2012)

# More detailed astrochemical modelling including deuterium




**Du et al. in prep**

**OD/HDO >> OH/$H_2O$**

**because there are more fractionation routes for OH than for $H_2O$**

**(D + OH → OD + H)**

# Perspectives

- Derive directly the OD/OH ratio observationally

  → Observation of $^{18}OH$ with SOFIA (Cycle I proposal rated A, not observed)

- Observation of OD towards other star-forming regions (tracing other physical conditions and history)

  → OD detected towards SgrB2 (Parise et al. in prep)
  + Cycle I accepted SOFIA proposal by Menten et al.