A non-equilibrium ortho-to-para ratio of H_2O in the Orion PDR

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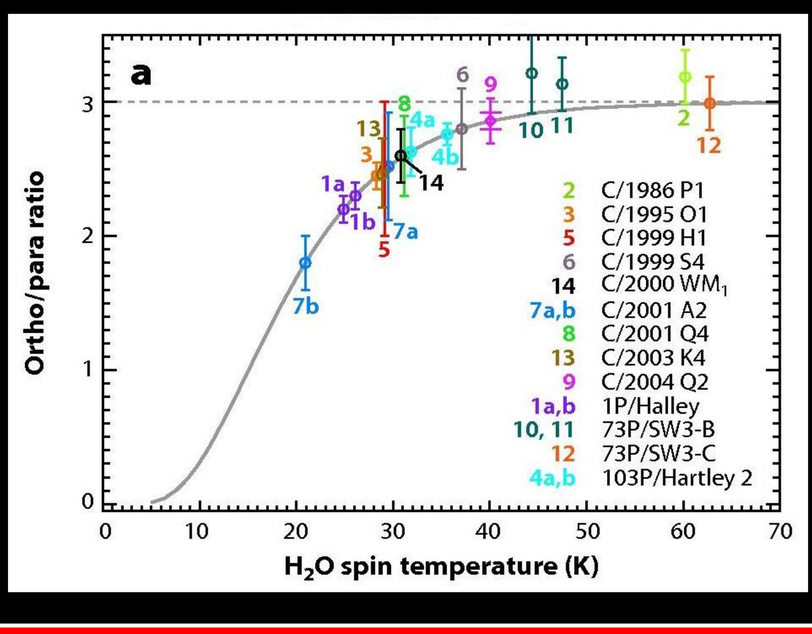
The ortho-to-para ratio (OPR) of H_2O

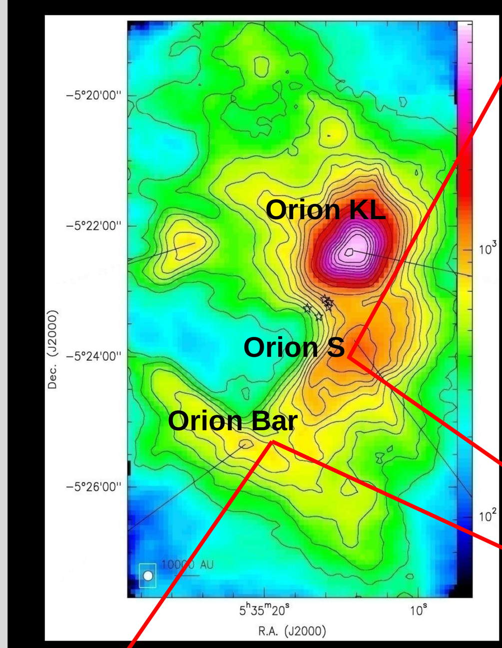
- Two species of molecular hydrogen
  - para-H_2 (↑↓)
  - ortho-H_2 (↑↑)
- The OPR is expected to be ~ 3 at high temperature (> 40 K).
- The OPR is lower than 1 at low temperature (< 15 K).
- OPR ~ 2 − 3 in solar system comets and interstellar medium (Mumma & Charnley 2011; Lis et al. 2010; Flagey et al. 2013)
- OPR ~ 0.77 in the protoplanetary disk TW Hya (Hogerheijde et al. 2011)



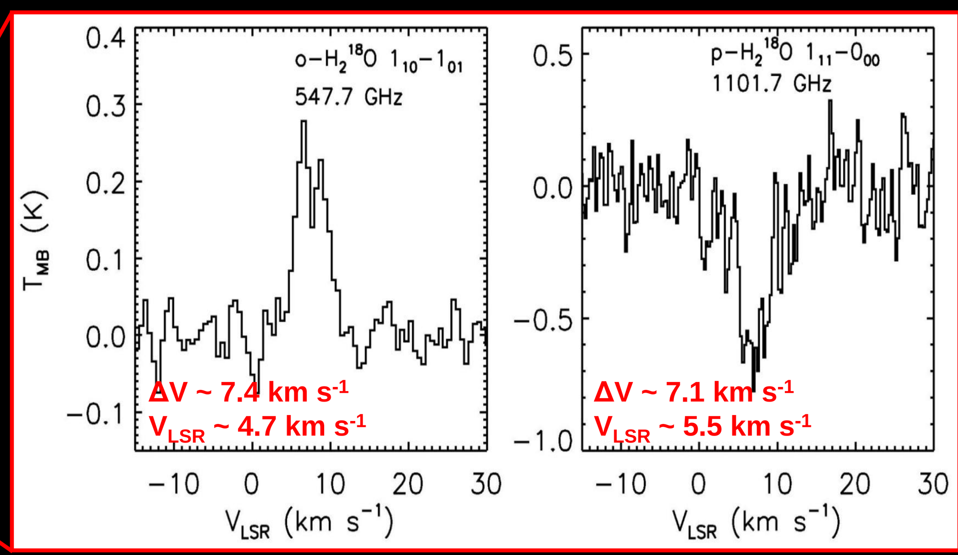
The ortho-to-para ratio of H_2O is useful to study the formation mechanism of water.

Sources & Observations

We observed the ground-state lines of ortho- and para-$H_2{}^{18}O$ in the Orion PDR (Photon-dominated region), at the Orion Bar and Orion S positions, as a part of the HEXOS (Herschel/HIFI Observations of EXtraOrdinary Sources, PI: E. A. Bergin) key program for the HIFI instrument onboard the Herschel Space Observatory.

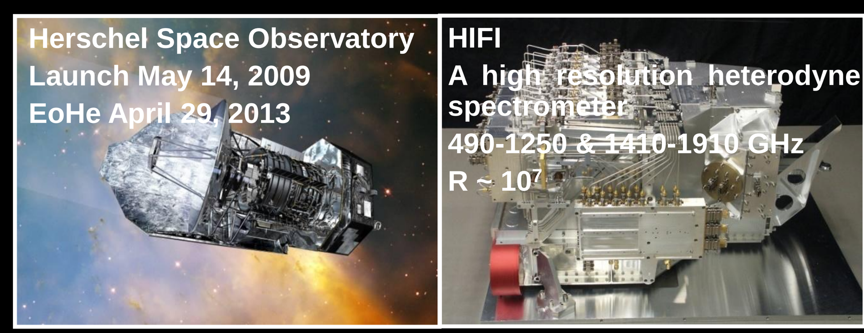


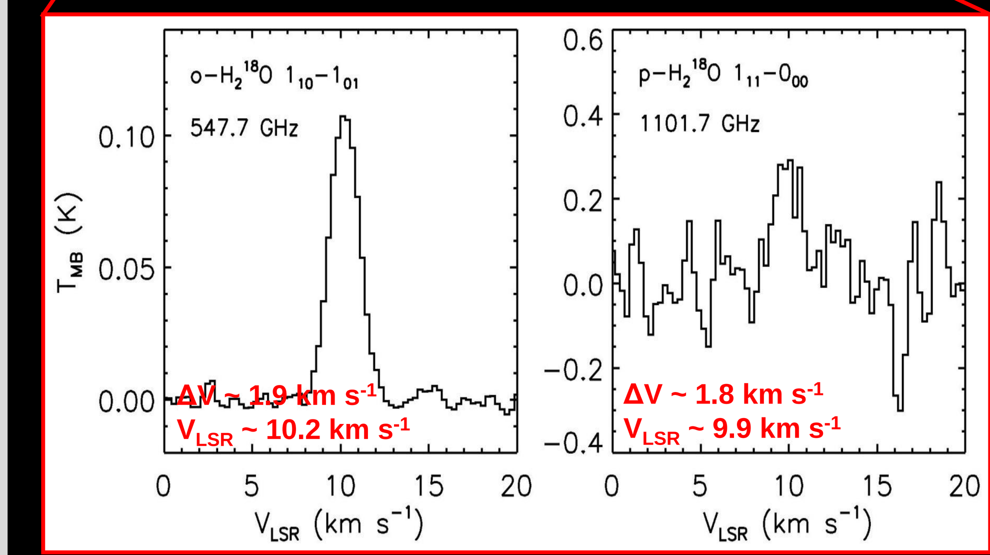
Color: CO 6-5 / Contour: CO 7-6
(Peng et al. 2012)



Orion S

- A star formation region located 2' south of Orion KL.
- Younger and more quiescent.





Orion Bar

- Nearly edge-on morphology
- Clumpy structure
- Distance ~ 414 pc
- Temperature ~ 85 K
- Mean density ~ 10^5 cm^{-3}

LTE Calculations

We assumed that
- the lines are optically thin (we do not see $H_2{}^{17}O$ lines).
- the gas is not warm (< 150 K, we do not see excited-state lines of $H_2{}^{18}O$).

Orion Bar

For T_{ex} = 50 − 100 K
- N(o-$H_2{}^{18}O$) ~ 3.0x10^{10} cm^{-2}
- N(p-$H_2{}^{18}O$) ~ 1.0x10^{11} cm^{-2}
- OPR ~ 0.3

Orion S

- N(o-$H_2{}^{18}O$) ~ 2.0x10^{11} cm^{-2} for T_{ex} = 50 − 100 K
- N(p-$H_2{}^{18}O$) ~ 2.0x10^{12} cm^{-2} from absorption depth
- OPR ~ 0.1

- **The OPR in LTE condition ~ 0.1 − 0.3**
- **much lower than the OPR in TW Hya .**

Discussion

The OPR of water in the Orion PDR is much lower than interstellar value.

- Beam size effect?
  : the sources are extended.
  : trace the same gas based on line width and velocity.
- Gas-phase formation of water?
  : H_3O^+ dissociative recombination is exothermic (OPR ~ 3).
- Water formation on grains, recent evaporation?
  : dust temperature is too low (< 100 K).
- Effect of photodesorption?
  - recombination of H + OH ⇒ H_2O (OPR ~ 3)
  - kick-out mechanism (low OPR)
  - the relative importance: ice thickness & ice temperature

This low OPR is inconsistent with gas phase formation and with thermal evaporation from dust grains. But it may be explained by photodesorption.

Non-LTE Calculations

We carried out non-LTE calculations of water using the RADEX code (van der Tak et al. 2007).

Orion Bar

- At T_{kin} = 20 K and $n(H_2)$ = 10^4 cm^{-3}
  OPR ~ 0.1
- At T_{kin} = 60 K and $n(H_2)$ = 10^6 cm^{-3}
  OPR ~ 0.1
- At T_{kin} = 100 K and $n(H_2)$ = 10^8 cm^{-3}
  OPR ~ 0.5

Orion S

- At T_{kin} = 60 K and $n(H_2)$ = 10^6 cm^{-3}
  OPR ~ 4
- At T_{kin} = 100 K and $n(H_2)$ = 10^8 cm^{-3}
  OPR ~ 0.3

- **Non-LTE results for the Orion Bar (OPR ~ 0.1 − 0.5) are in good agreement with LTE calculations.**
- **The OPR in the Orion S (~ 0.3 − 4) depends on conditions.**

References
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