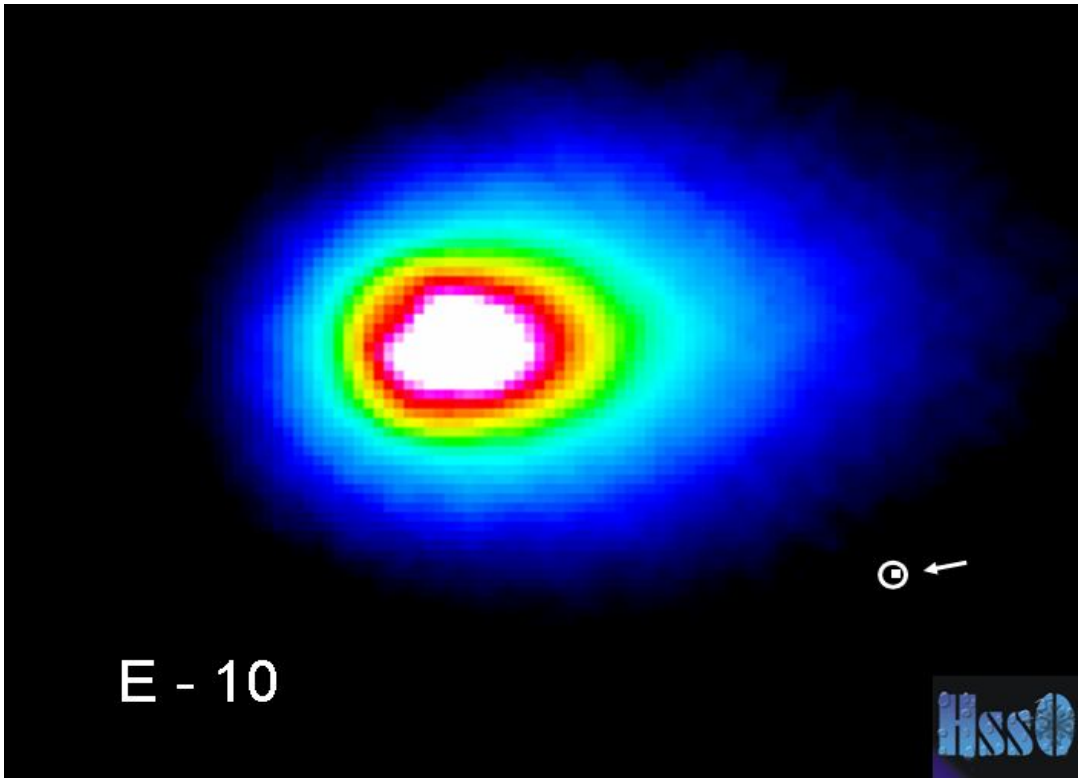
Ocean-like water in 103P/Hartley 2



Paul Hartogh[1], Dariusz C. Lis, Dominique Bockelée-Morvan, Miguel de Val-Borro, Nicolas Biver, Michael Küppers, Martin Emprechtinger, Edwin A. Bergin, Jacques Crovisier, Miriam Rengel, Raphael Moreno, Slawomira Szutowicz & Geoffrey A. Blake and the HssO team

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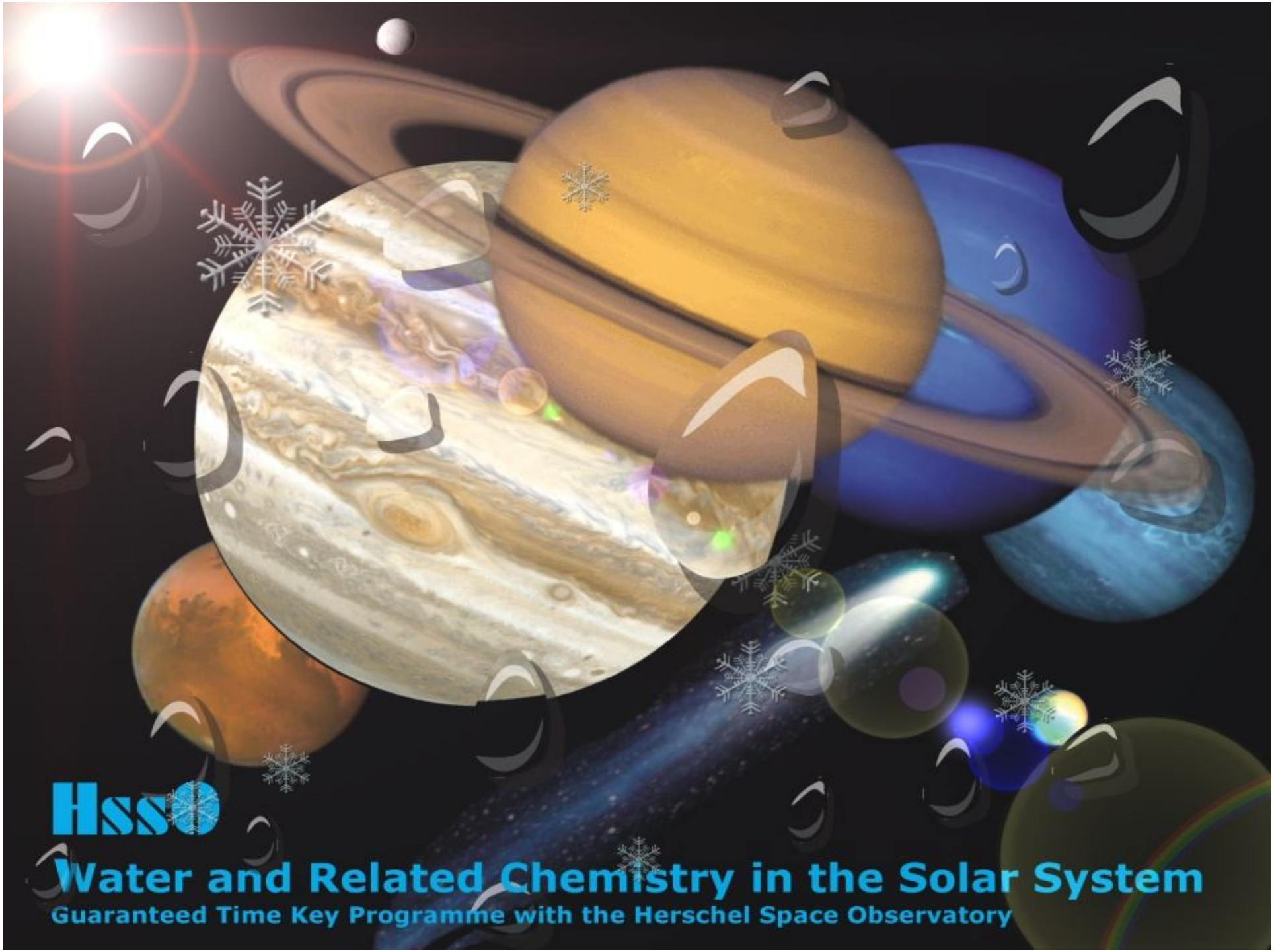


Main HssO Goals

- Origin of water in the stratospheres of the gas and ice giants and Titan
- Mars water cycle and atmospheric composition
- Constrain water excitation models of cometary atmospheres.
- D/H in comets & first detection of D/H in JFC

Hartogh et al. (2009), PSS

http://www.mps.mpg.de/projects/herschel/HssO/index.htm

Modeling cometary line shapes

- Two methods:
  - Accelerated Monte Carlo radioative transfer (Hogerheijde & van der Tak, 2000; Bensch & Bergin 2004)
  - Sobolev escape probability method (Bockeleé-Morvan 1987; Biver 1997).

C/2008 Q3 (Garradd)

Credit: JPL
Wide-field Infrared Survey Explorer (WISE)

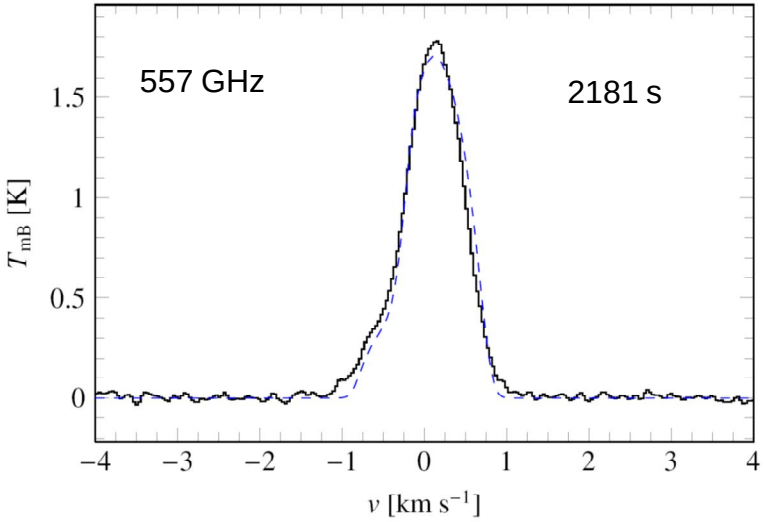
- A long-period comet (P = 190,000 yr) from the Oort cloud
- Distance : perihelion on 23 Jun. 2009 at 1.8 AU

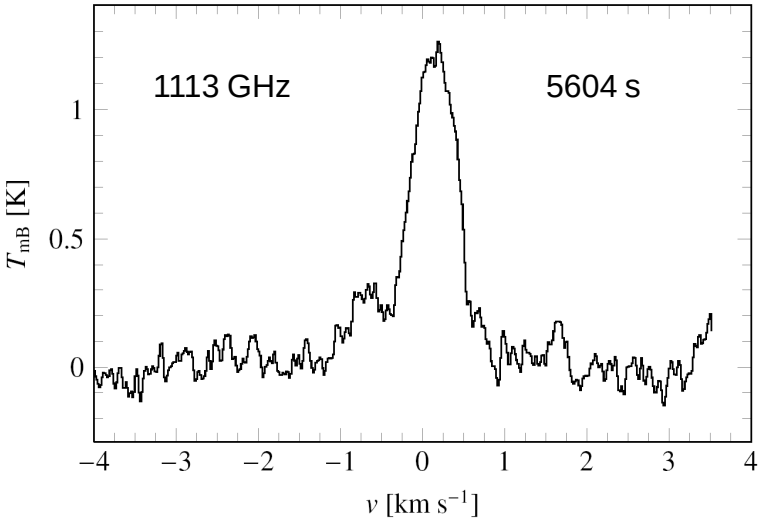
- Rather Bright (mv = ~ 7 @1.8 AU)
- Date of observations: 20 – 27 July 2009 at 1.9 AU (Sun) and 1.8 AU (Herschel)

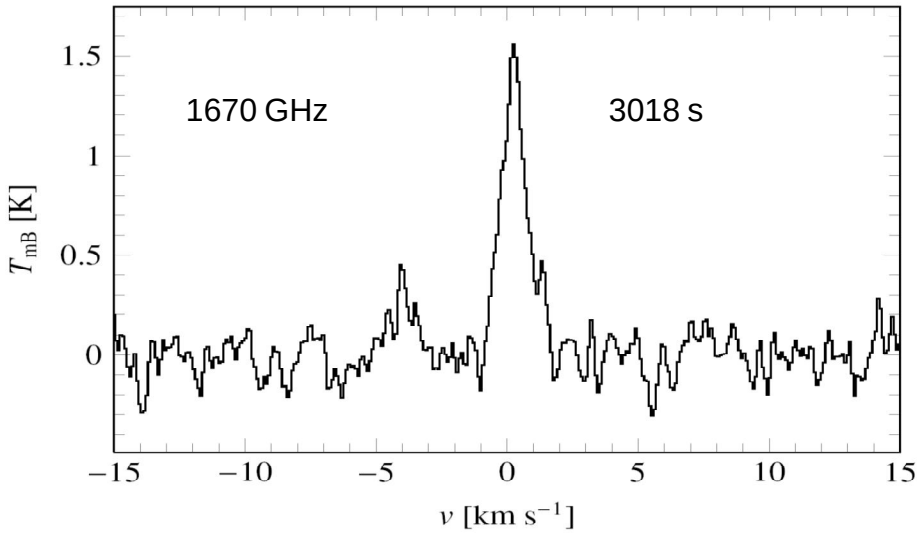
HIFI observations

- Water lines:
  - 110-101 (ortho) 556.936 GHz 38.1 ’’ (51000 km)
  - 111-000 (para) 1113.343 GHz 19.2 ’’ (34000 km)
  - 212-101 (ortho) 1669.9 GHz 12.7 ’’ (17000 km)
- First detection in a comet (lower 2 lines)
- Frequency Switch: throw = 92 MHz
- Position Switch: off pos. 0.5 deg from comet

All lines in FSw mode



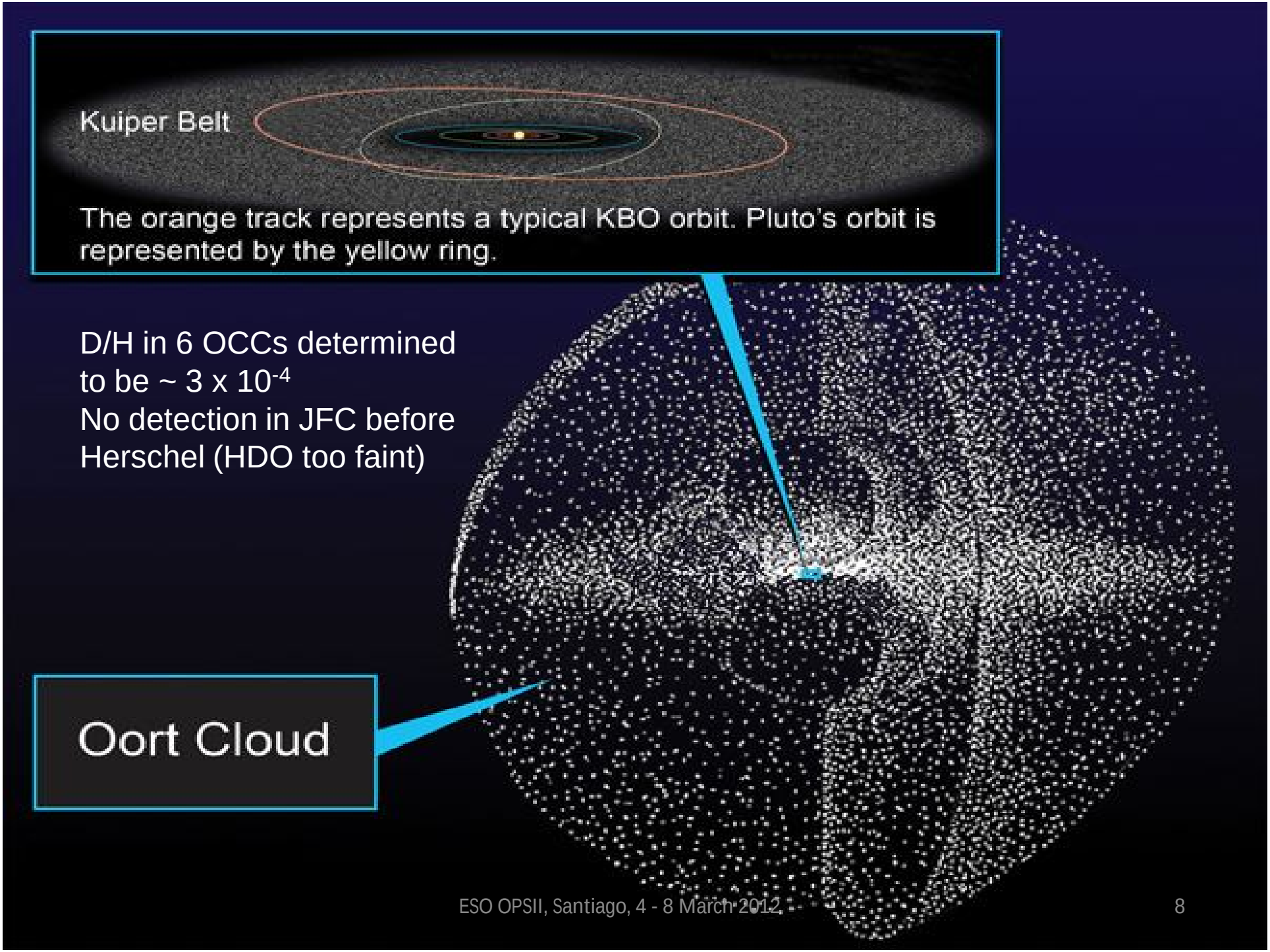




Observed relative line intensities in good agreement with models.

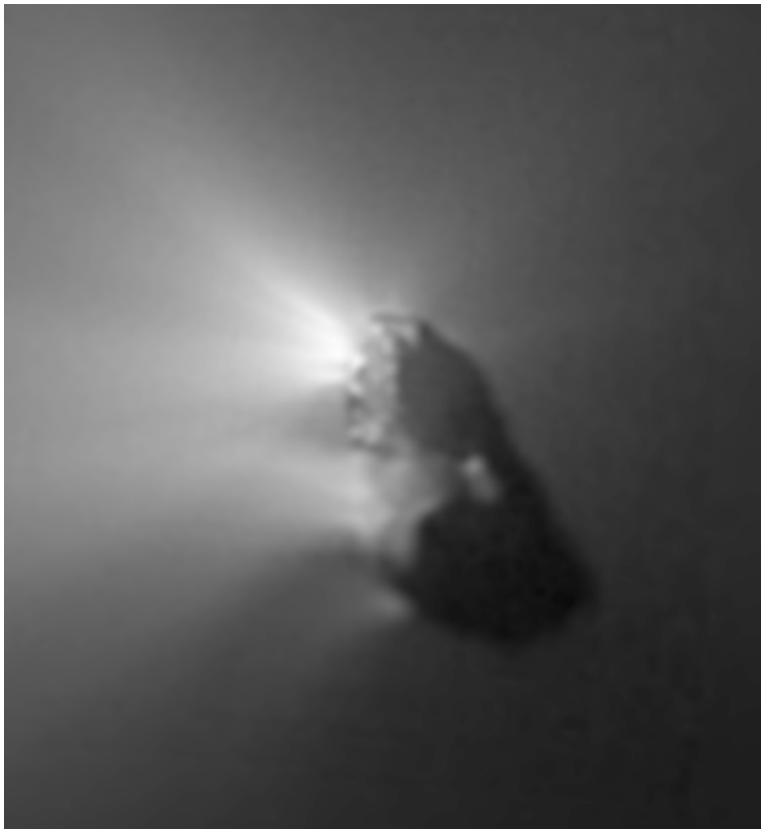
Models agree within 5%

Hartogh et al. (2010), A&A



103P/Hartley 2

Credit: NASA/EPOXI



Credit: MPS/HMC

1P/Halley

First detection of D/H in a JFC

- Observation of 103P/Hartley 2 with all Herschel instruments near perihel in fall 2010

- Spectroscopic observations of water isotopes with the very high resolution ($4x10^6$) “Heterodyne Instrument for the Far Infrared”, HIFI on 17 November 2010

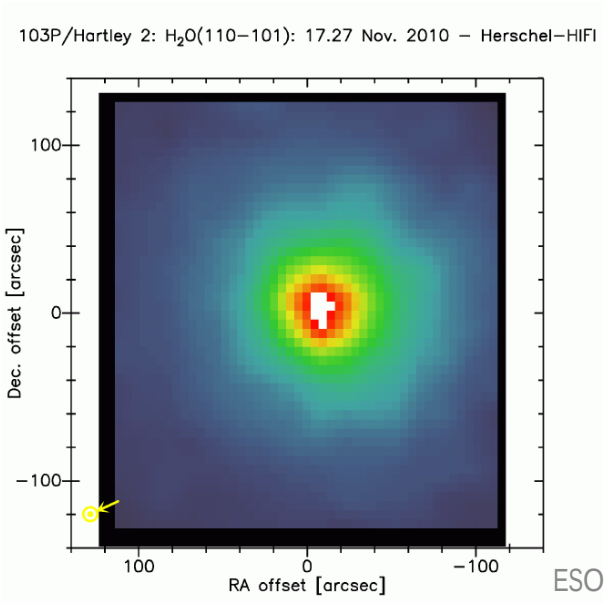
Variability of 103P: Alternating observations

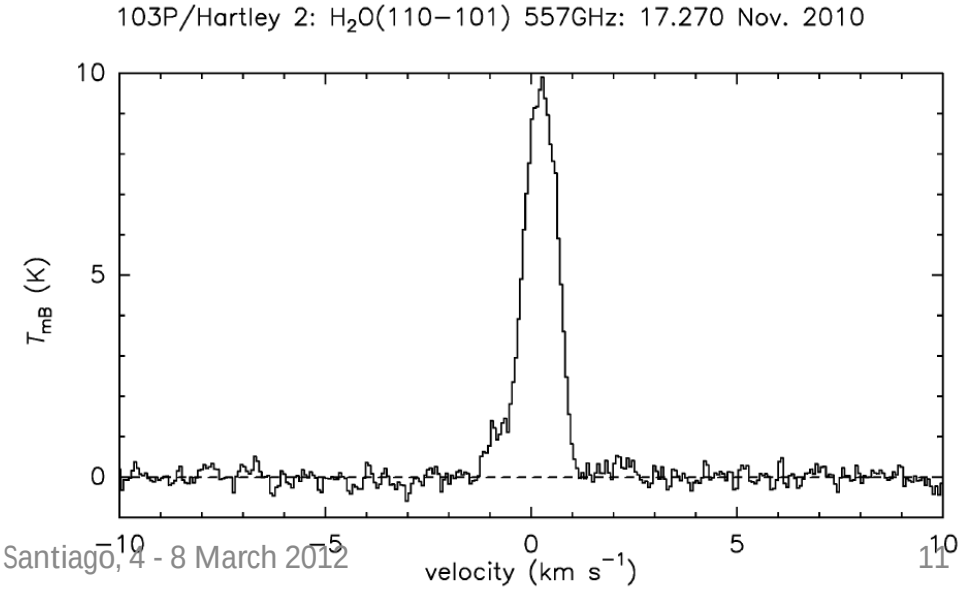
Date: 17.28 – 17.64 November 2010

11 observations of H_2O (557 GHz) + $H_2{}^{18}O$ (548 GHz) with 10 of HDO (509 GHz) and five maps of H_2O: total 66 + 320 + 80min (~8h)

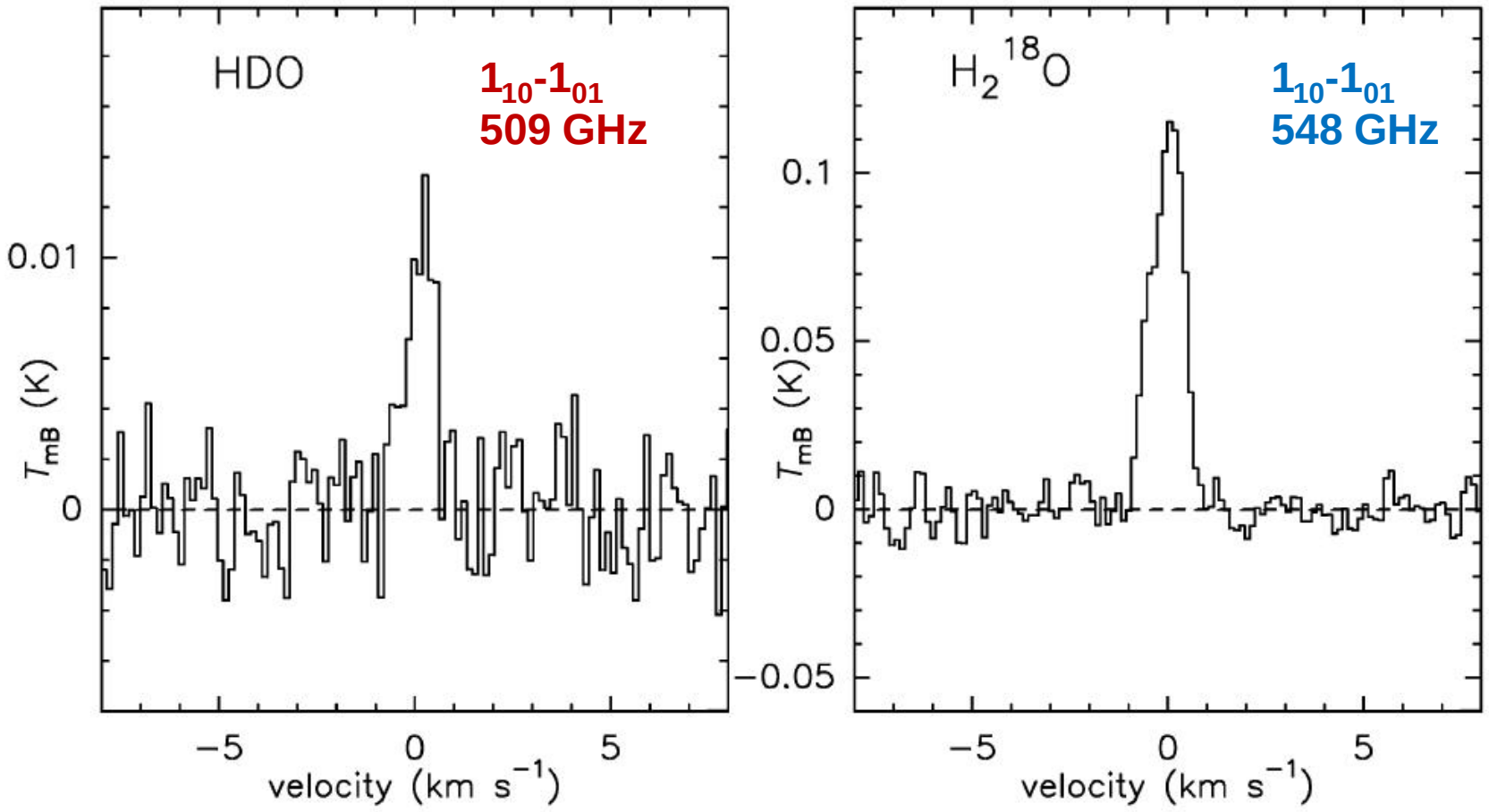
Same receiver, same HIFI band → similar field of view (~39'', 6500 km)

Observed variation: smooth decrease by ~20% of Q_{H2O} during the observation





Observed spectra:



S/N = 10

S/N = 60

Analysis of the observations

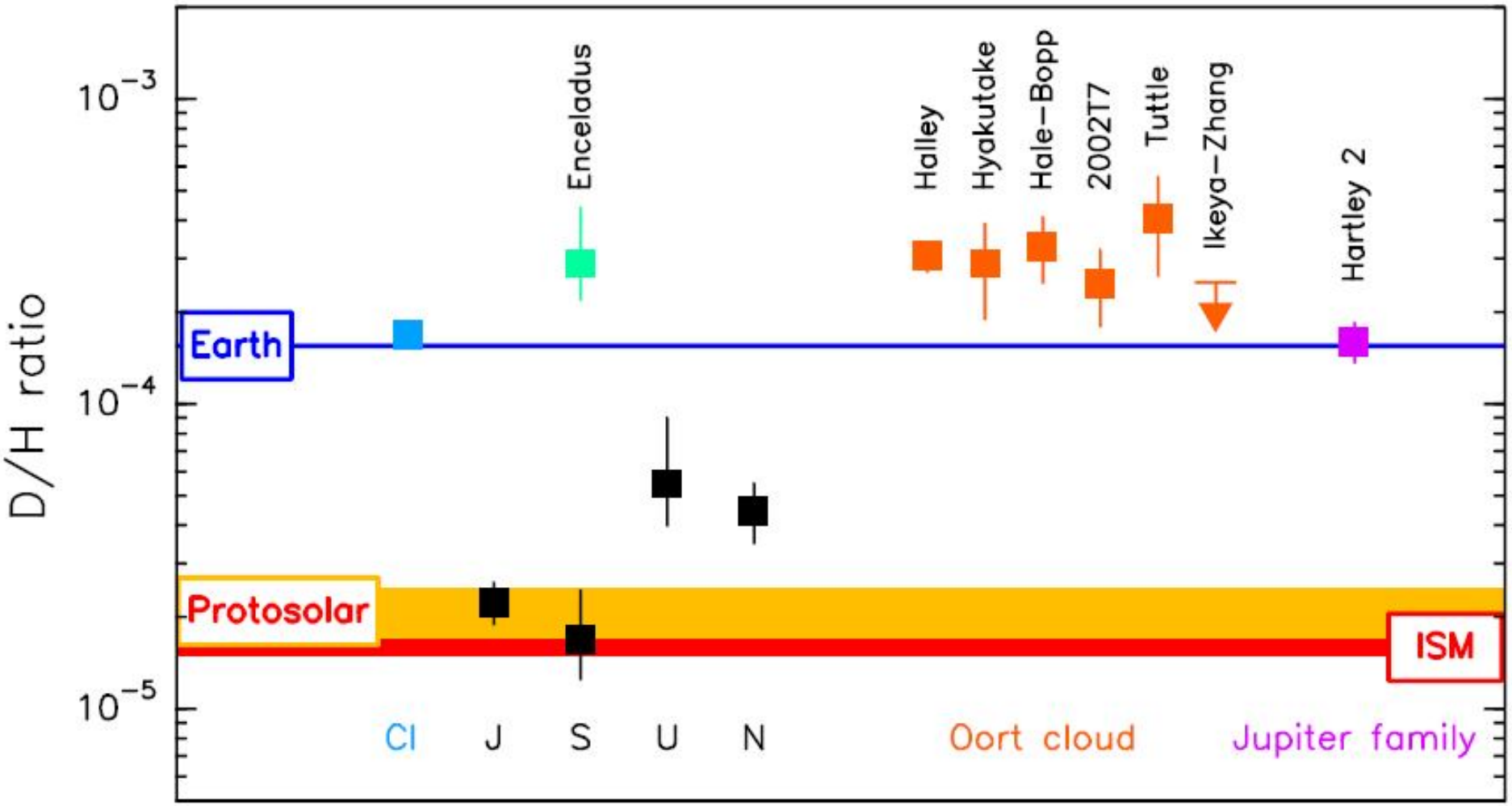
- Excitation model : collisions with H_2O, electrons and infrared pumping, gas temperature determined by other observation (e.g. methanol lines at IRAM/CSO/SMT)

- → the $HDO/H_2{}^{18}O$ production rate ratio is not very sensitive to the model parameters (similar transition: $J = 1_{10}\text{-}1_{01}$)

- Hypothesis : $^{16}O/^{18}O = 500$ (+/- 10%) (VSMOW)
  (520±30 in 4 comets with Odin)

=> **$D/H = (1.61 \pm 0.24) \times 10^{-4}$**

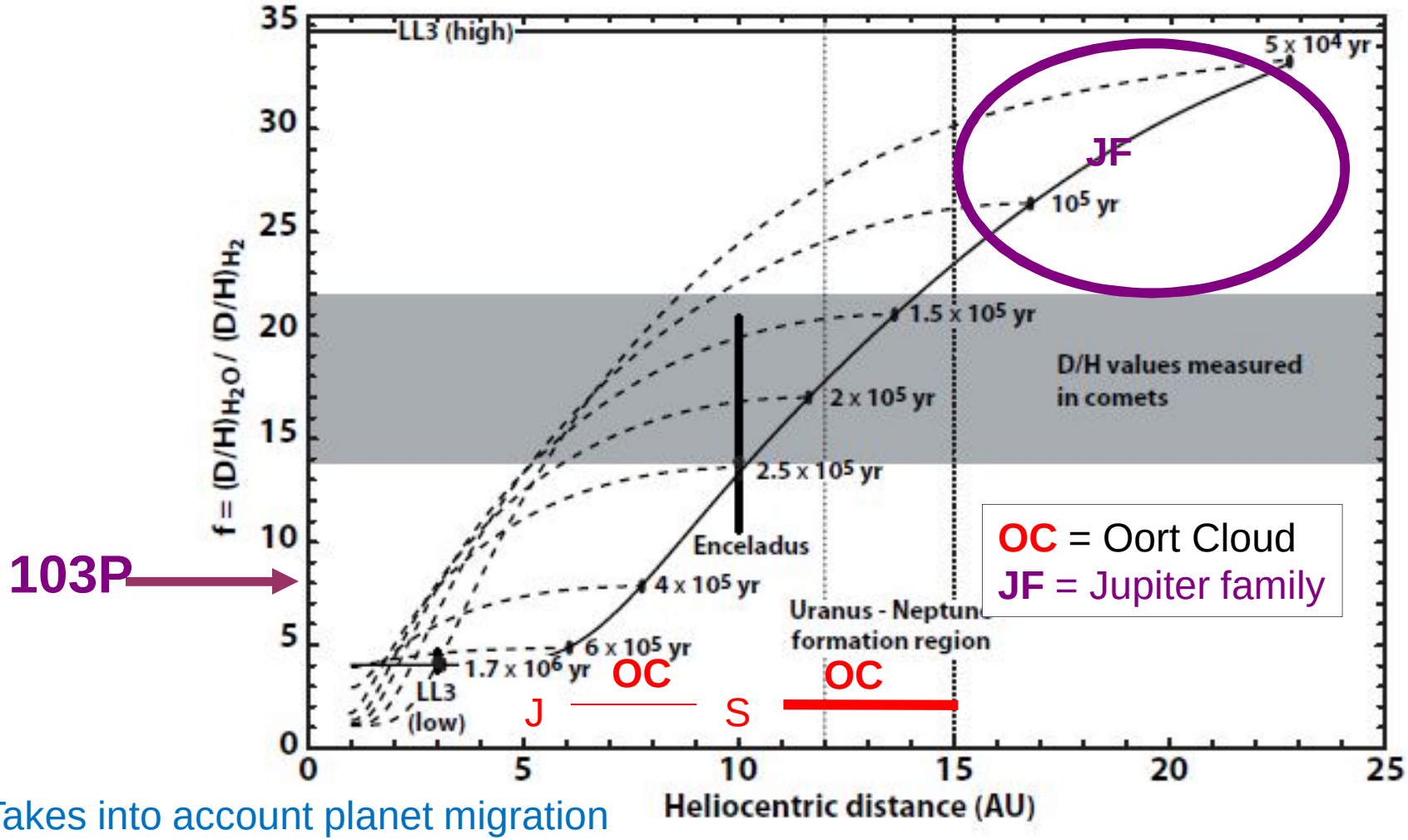
$D/H(VSMOW) = 1.558 \pm 0.001 \times 10^{-4}$



Hartogh et al. (2011), Nature

D/H model for the solar system

Kavelaars et al. (2011)



Takes into account planet migration

What could be wrong?

- Model of D/H fractionation with heliocentric distance?
- 103P may not come from the Kuiper belt. Is it a Trojan (Horner et al. 2007) originating near Jupiter?
- Perhaps OCCs did not form in the vicinity of the giant planets and/or do not represent the solar system at all (Levison et al, 2010)
- In the early phase of the solar system formation material was mixed over large distances (Walsh, 2011).
- Models of the dynamical evolution of the solar system?

- What about delivery of water to Earth?

Earth accreted wet

- Wänke: Heterogeneous accretion. 3 phases of accretion with a late third phase (~ 1% of Earth mass) providing also water

Phil. Trans. R. Soc. Lond. 303, (1981)

- *Morbidelli, M&PS, (2001): early delivery of water by a few planetary embryos formed in the outer asteroid belt. Maximum 10 % water delivered by comets*

Origin of water in the terrestrial planets

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M&PS 40 (2005)

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Abstract–I examine the origin of water in the terrestrial planets. Late-stage delivery of water from asteroidal and cometary sources appears to be ruled out by isotopic and molecular ratio considerations, unless either comets and asteroids currently sampled spectroscopically and by meteorites are unlike those falling to Earth 4.5 Ga ago, or our measurements are not representative of those bodies. However, the terrestrial planets were bathed in a gas of H, He, and O. The dominant gas phase species were H_2, He, H_2O, and CO. Thus, grains in the accretion disk must have been exposed to and adsorbed H_2 and water. Here I conduct a preliminary analysis of the efficacy of nebular gas adsorption as a mechanism by which the terrestrial planets accreted "wet." A simple model suggests that grains accreted to Earth could have adsorbed 1–3 Earth oceans of water. The fraction of this water retained during accretion is unknown, but these results suggest that examining the role of adsorption

Earth accreted dry

- *Javoy, E&PS 2010: Earth bulk isotopic composition similar to E-chondrites. Volatiles were delivered later.*

- *Gomes et al, 2005: sudden massive delivery of planetesimals from the trans-Neptunian region to the inner Solar System caused by rapid migration of the giant planets, (LHB). Comets provided maximum 6 % of the water on Earth, compatible with the D/H measurement in comets.*

Summary

- Ocean like water found for the first time in a comet
- Finding does not fit present models on origin of cometary material and/or isotopic fractionation with heliocentric distance.
- Paradigma of maximum 10 % cometary water in hydrosphere based on composition arguments disproved.