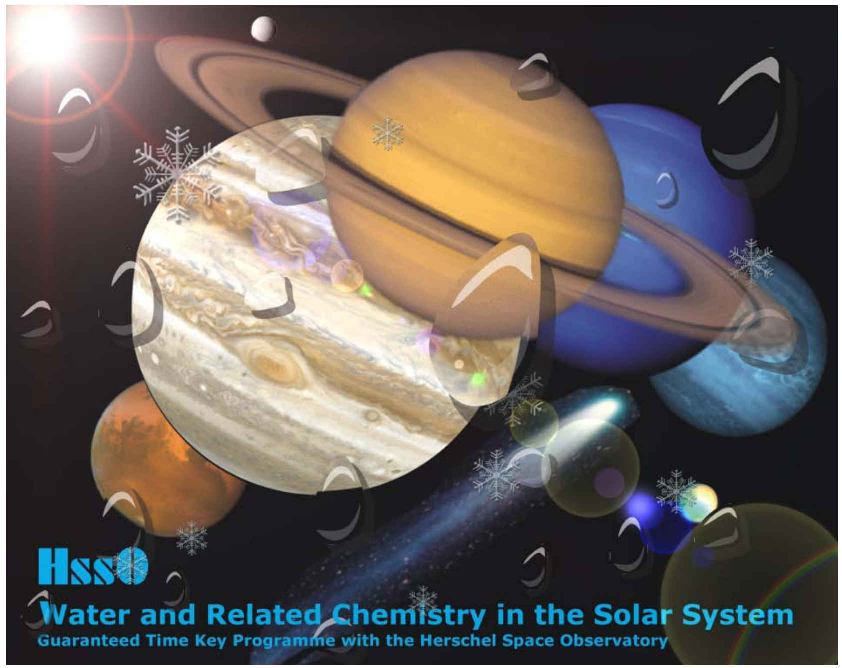
First Solar System observations with Herschel



Paul Hartogh, Jacques Crovisier, Emmanuel Lellouch, Nicolas Biver, Dominique Bockelée-Morvan, Miguel de Val-Borro, Bruce Swinyard, Sunil Sidher, Helmut Feuchtgruber, Christopher Jarchow, Raphael Moreno, Miriam Rengel, Bart Vandenbussche and the HssO Team

AAS 216th Meeting, 23-27 May 2010, Miami, FL

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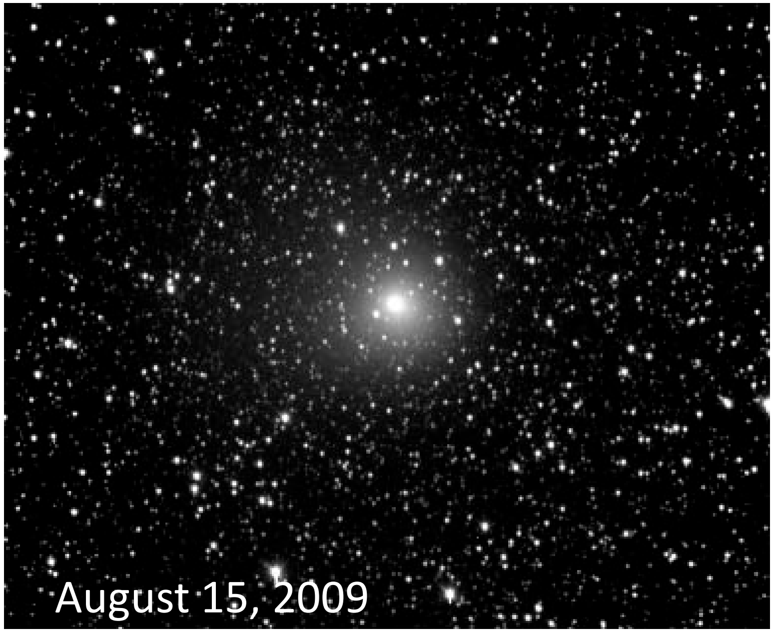
- *Helen Walker*

Outline

- Comet C/2006 W3 Christensen PACS/SPIRE
- Comet C/2008 Q3 Garradd with HIFI
- Neptune methane with PACS
- Mars CO and water with SPIRE

Observations of comet C/2006 W3 (Christensen)



Credit : Rok Palcic

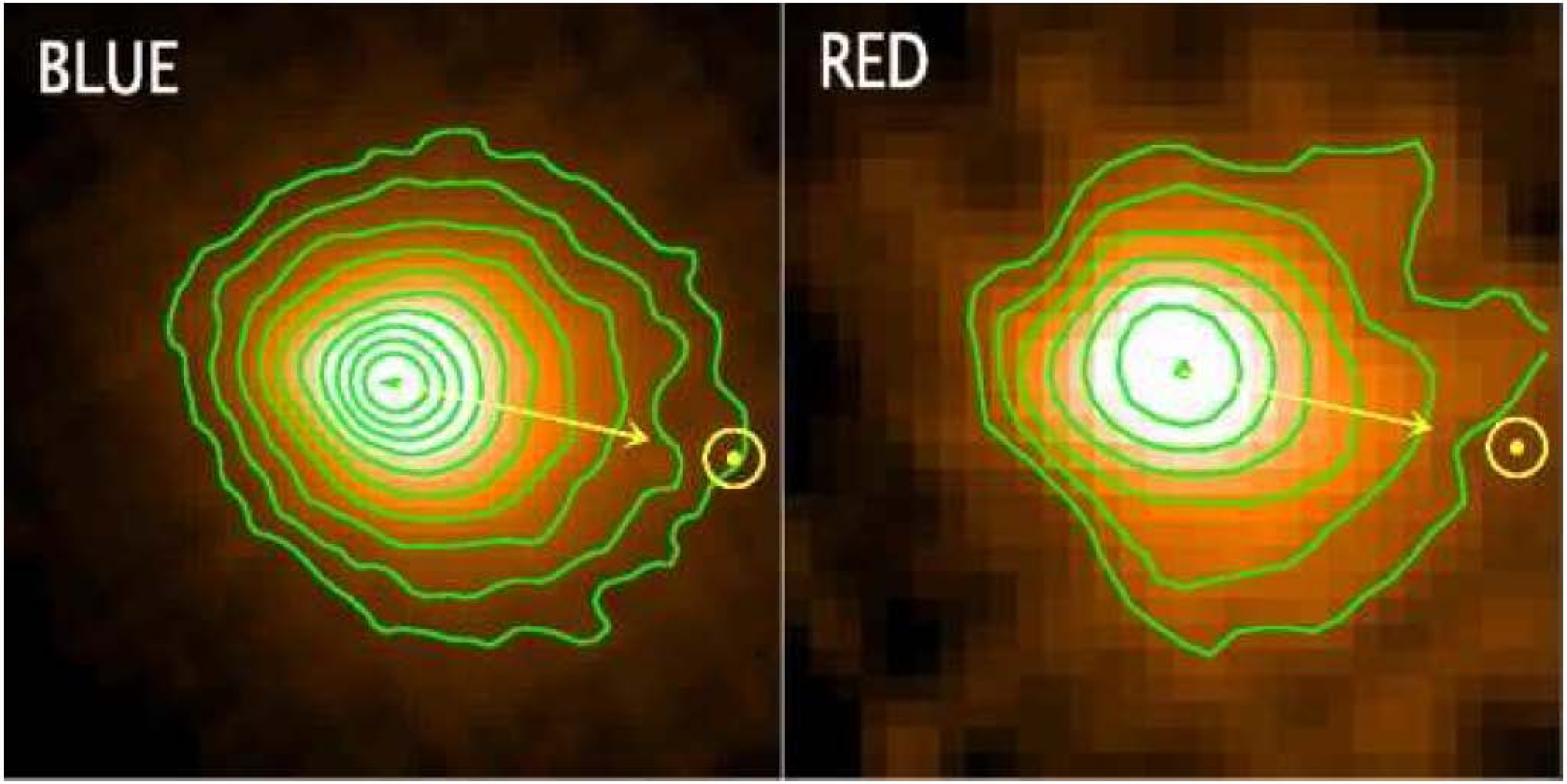
- A long-period comet (P = 140,000 yr) from the Oort cloud
- Distant : perihelion on 6 Jul. 2009 at 3.13 AU from the Sun
- Bright (mv = 8.5 @3.1 AU) suggesting activity driven by the release of hypervolatiles (CO, CO_2)
- OH Nançay observations @3.3 AU pre-perihelion:
  water production rate $Q(H_2O) = 5 \times 10^{28}$ mol/s
- A weak target for investigation of H_2O lines using PACS/SPIRE on Herschel

Observations of C/2006 W3 (Christensen) with the Herschel Space Observatory

- PACS (1 & 8 Nov. 2009)
  - Photometer maps (red & blue)
  - Dedicated line spectroscopy : 5 water lines at 108.15, 138.6, 174.75, 179.65 and 180.61 μm
  - SED range scans
- SPIRE (8 Nov. 2009)
  - High resolution spectral scan, sparse image sampling

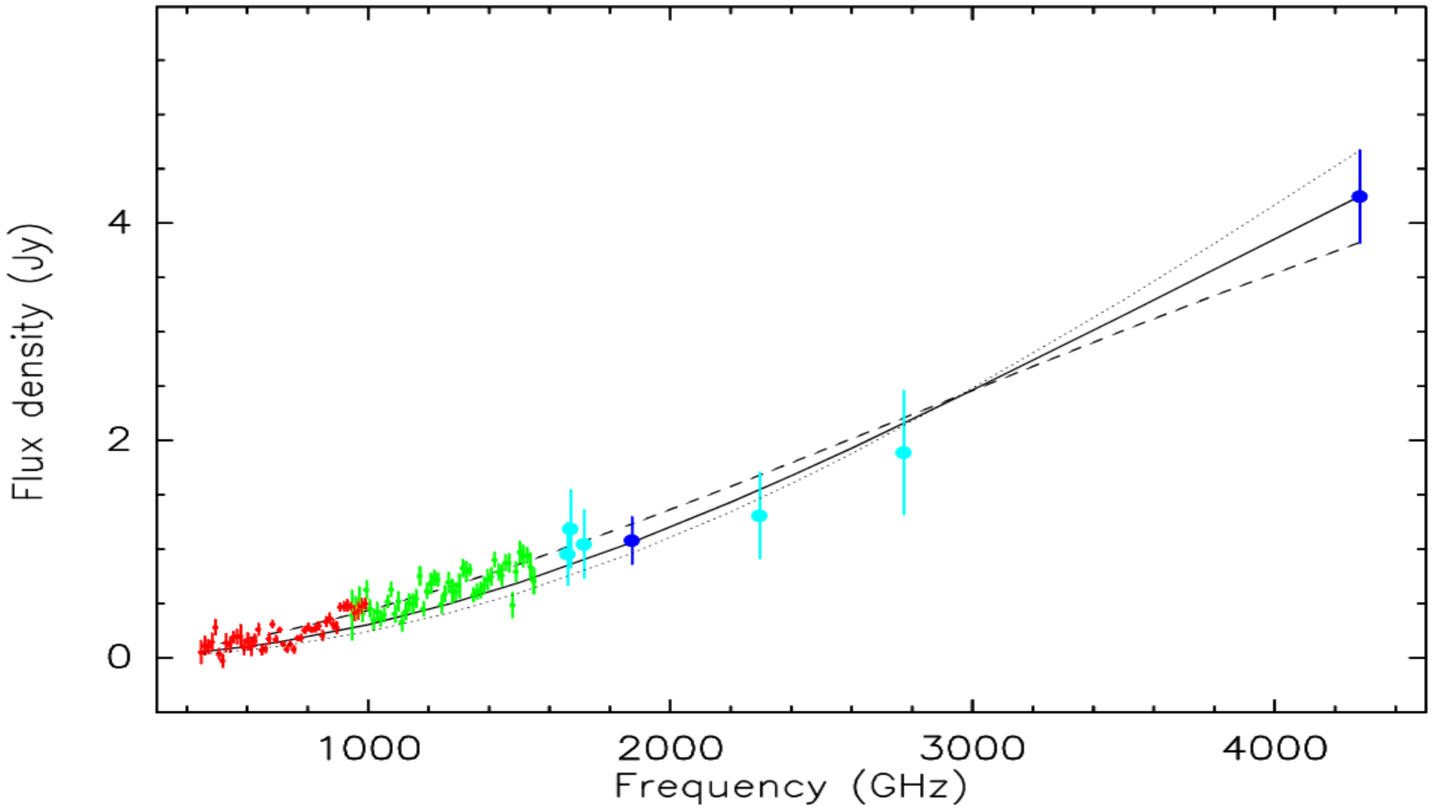
Comet imaging with PACS
The dust coma is resolved

1’ x 1’ (1’=1.6 x10^5 km) 1’ x 1’



70 µm 160 µm

PACS & SPIRE SEDs: large particles



Model for amorphous grains with 0.9 mm diameter fits best

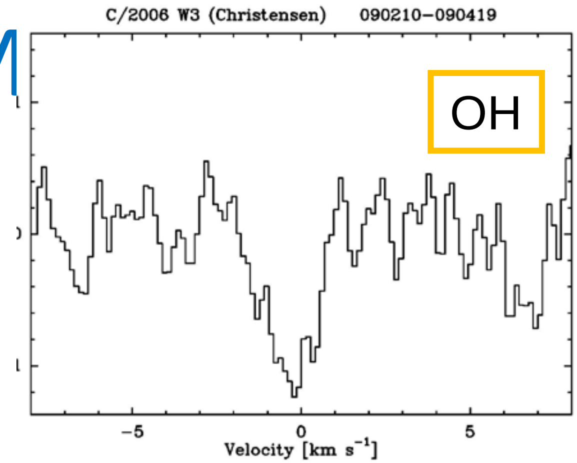
Supporting observations at Nançay and IRAM

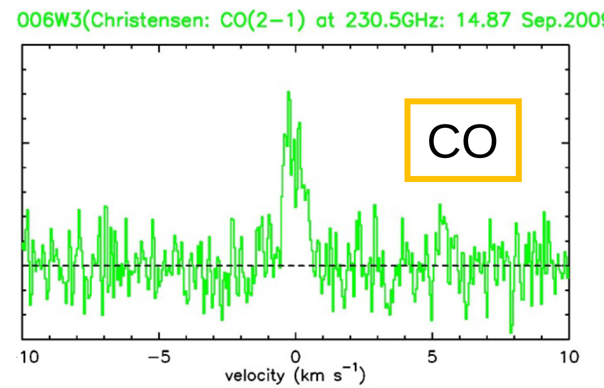
• 2-Jan.-2009 → 19 Apr. 2009: OH (18 cm) radical at Nançay
r_h = 3.60-3.20 AU: $Q_{H2O} = 5 \pm 1 \times 10^{28}$ at r_h=3.3 AU
•12 → 14 Sep. 2009: HCN, CH_3OH, CS, H_2S, CO at 30-m
r_h = 3.2 AU, D = 2.58 AU
• 29 Oct. 2009 : HCN and CO at IRAM 30-m
r_h = 3.32 AU, D = 3.48 AU

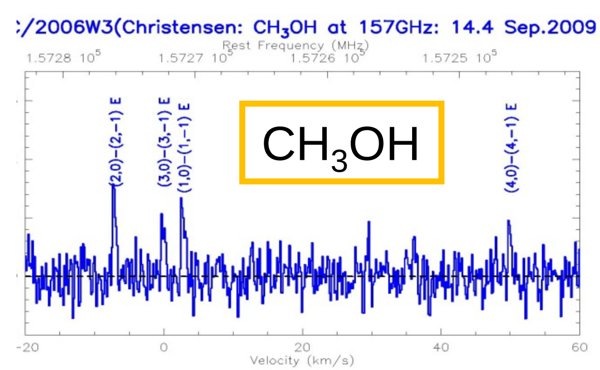
✓Measure pre-perihelion H_2O production rate

✓ Investigate species of different volatilities to constrain sublimation processes in comet nuclei

✓ Measure the gas temperature and velocity to interpret H_2O Herschel observations
→ T_{gas} = 18 K v_{gas} = 0.5 km/s

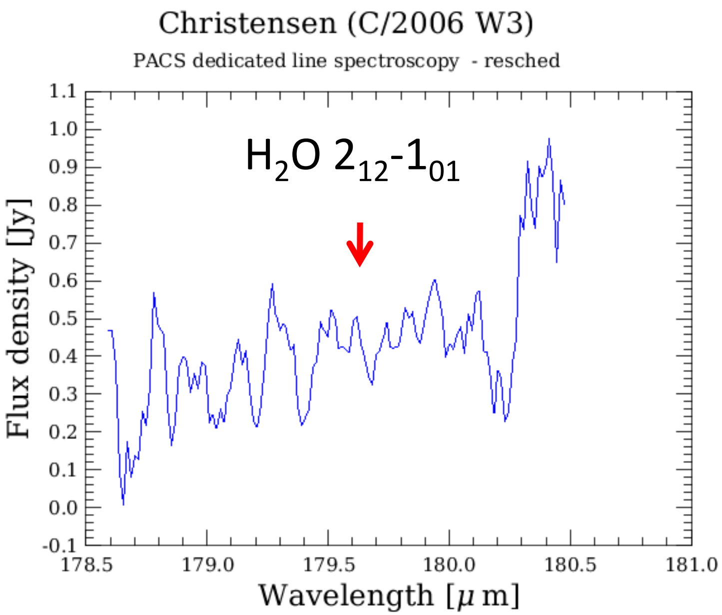


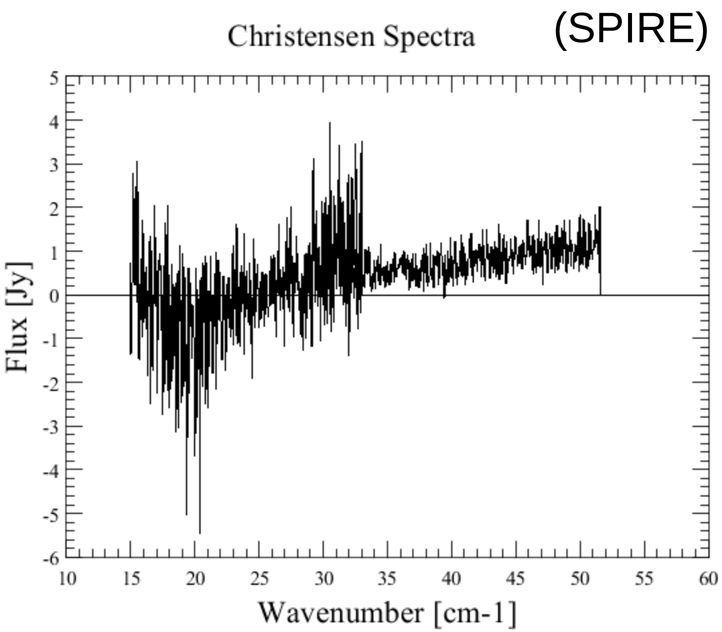




Spectroscopy with PACS and SPIRE

H_2O lines are not detected





- PACS : Expected strongest H_2O line : 2_{12}-1_{01} @179.65 μm = 1669.9 GHz
- SPIRE: Expected strongest H_2O line : 1_{11}-0_{00} @37.1 cm^{-1} = 1113 GHz
- Excitation and radiative transfer modelling with a coma temperature of 18 K
- 3-sigma upper limits on the water production rate :

PACS: $Q(H_2O) < 1.2 \times 10^{28}$ mol/s SPIRE: $Q(H_2O) < 6 \times 10^{28}$ mol/s

C/2006 W3 (Christensen) - Results

Spectroscopy

✓ Strong pre-post perihelion asymmetry in water production at 3.3 AU

→ Pre-perihelion : sublimation from icy grains ?

✓ coma dominated by CO : $Q(CO)/Q(H_2O) > 300$ %

(2 to 20 % in comets at ~ 1 AU from the Sun)

✓ coma strongly enriched in species more volatile than water

(compared to comets at ~ 1 AU)

→ analogy with Hale-Bopp coma composition at 3.3 AU

→ suggests Christensen 's nucleus to be CO-rich and of very low thermal inertia

Photometry (preliminary)

✓ Nucleus radius ~ 20 km

✓ Dust production rate : ~ 850 kg/s (carbon) ~ 920 kg/s (olivine)

✓ Dust-to-gas ratio ~ 0.5 – 1.4

Bockelee et al. 2010, A&A in press

C/2008 Q3 (Garradd)

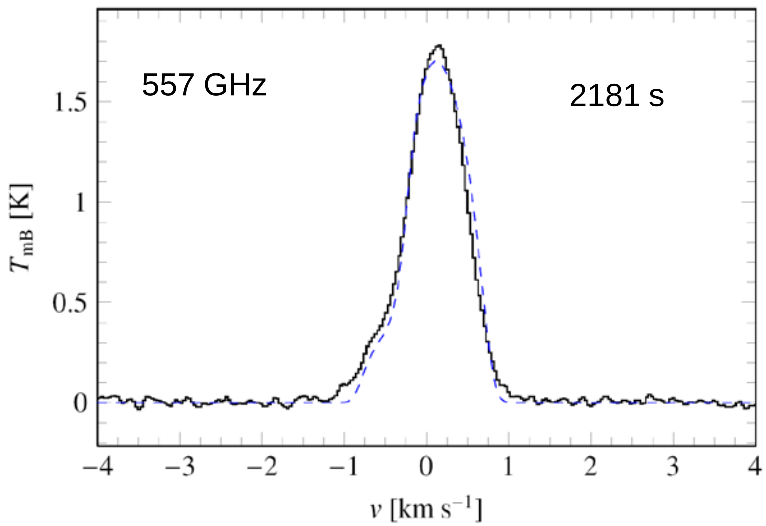
- A long-period comet (P = 190,000 yr) from the Oort cloud
- Distance : perihelion on 23 Jun. 2009 at 1.8 AU
  from Herschel
- Rather Bright (mv = ~ 7 @1.8 AU)
- Date of observations: 20 – 27 July 2010 at 1.8 AU (Sun) and 1.9 AU (Herschel)

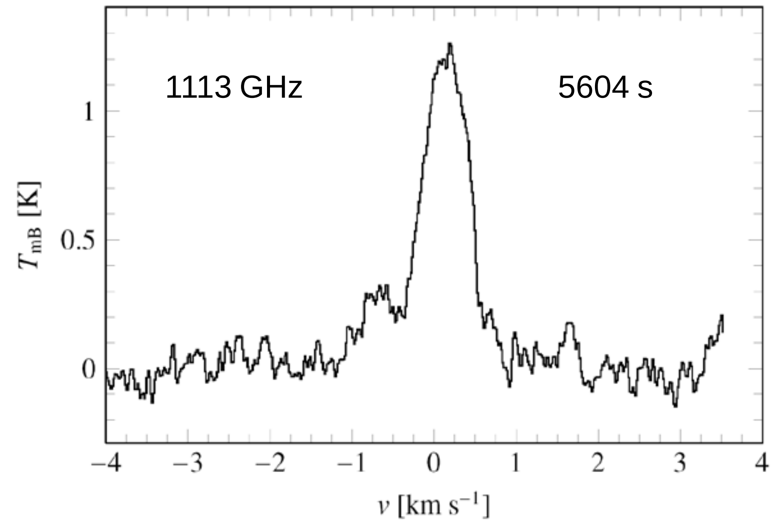
Credit: JPL
Wide-field Infrared
Survey Explorer (WISE)

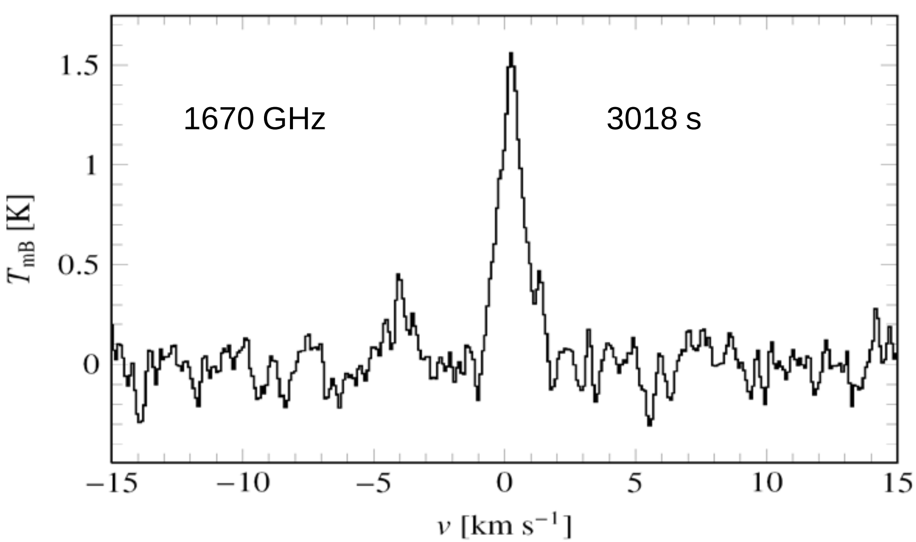
HIFI observations

- Water lines:
  - 110-101 (ortho) 556.936 GHz 38.1 ’’ (17000 km)
  - 111-000 (para) 1113.343 GHz 19.2 ’’ (34000 km)
  - 212-101 (ortho) 1669.9 GHz 12.7 ’’ (51000 km)
- First detection in a comet (lower 2 lines)
- Better constraints on excitation models

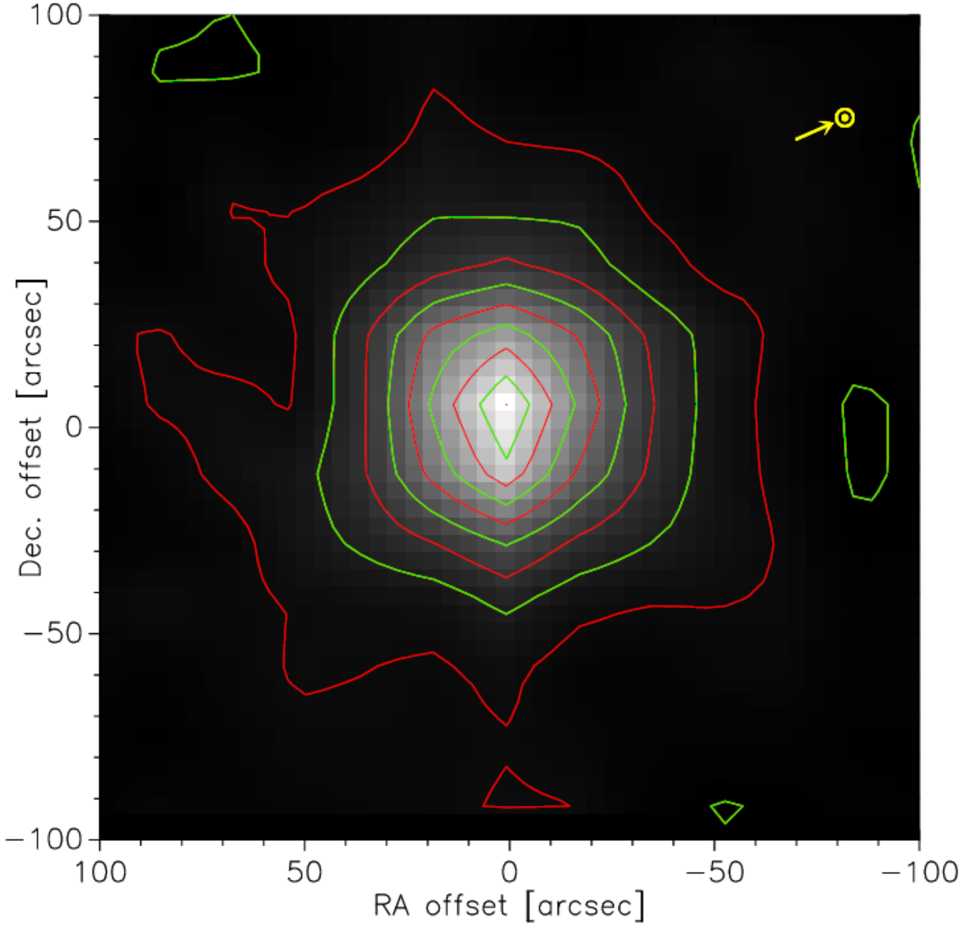
All lines in FSw mode





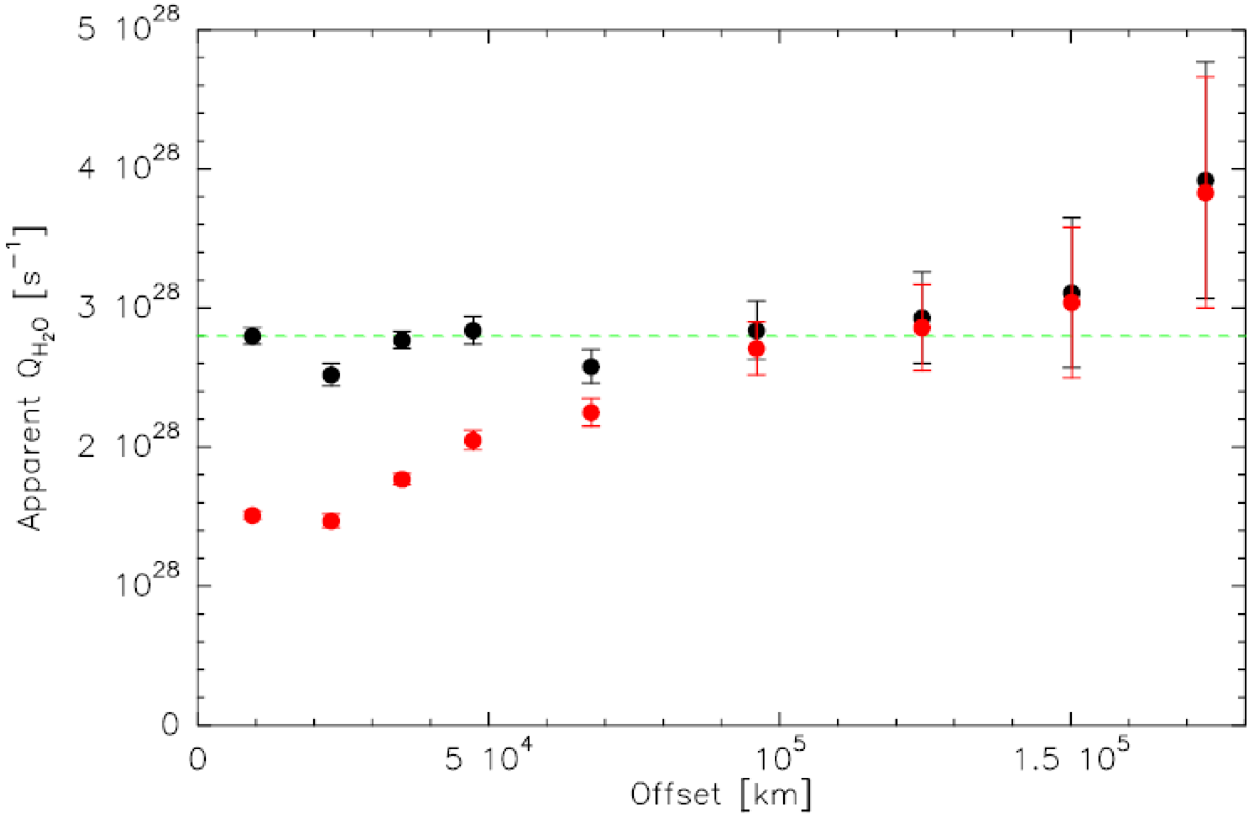


OTF map of C/2008 Q3 at 557 GHz



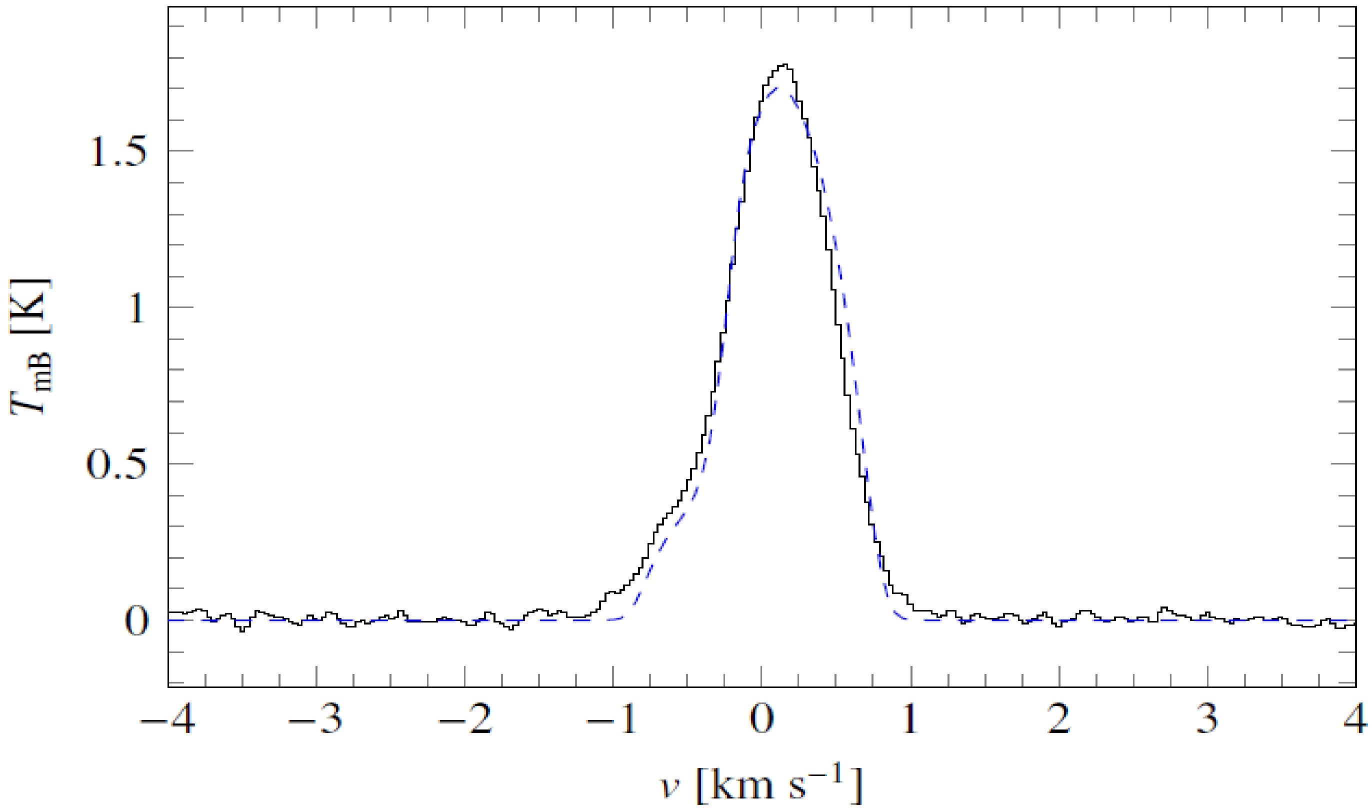
- Contours: 0.2 K km/s from 0 – 1.8 K km/s
- Map width: 300000 km
- Constrain Xne and neutral gas temperature by minimizing radial variation of water production rate at different offset positions

Water production rate for Xne = 0.2 (black) and 1



Black: Xne = 0.1 – 0.2, T=15 - 25 K

Optimal fit of observation from 20 July 2009



Expansion velocity = 550 m/s, Xne = 0.2 and T=15 K
Q[H2O] = 2.73 ± 0.01 x 10^28/s)

Production rates at 22/27 July 2009

22 July 2009 (1113 GHz) : 1.8 ±0.03 x 10^28 / s

27 July 2009 (1670 GHz) : 2.1 ±0.30 x 10^28 / s

27 July 2009 (1113 GHz) : 1.7 ±0.03 x 10^28 / s

Results on C/2008 Q3

HIFI observations of Comet C/2008 on 20-27 July 2009

First detection of the 111-000 and 212-101 rotational transitions in a comet

Derived parameters:

- Neutral gas temperature: 15 K
- Gas expansion velocity: 0.55 km/s
- Water production rates: 1.7 – 2.7 x 10^28/s

Decrease of production rates from 20 – 27 July 2009

Hartogh et al. 2010, A&A in press

Methane in the stratosphere of Neptune

- Methane is the third most abundant species in the Giant Planets, after H_2 and He; it is very abundant in Neptune's troposphere (~ 4 %), being responsible for Neptune's color

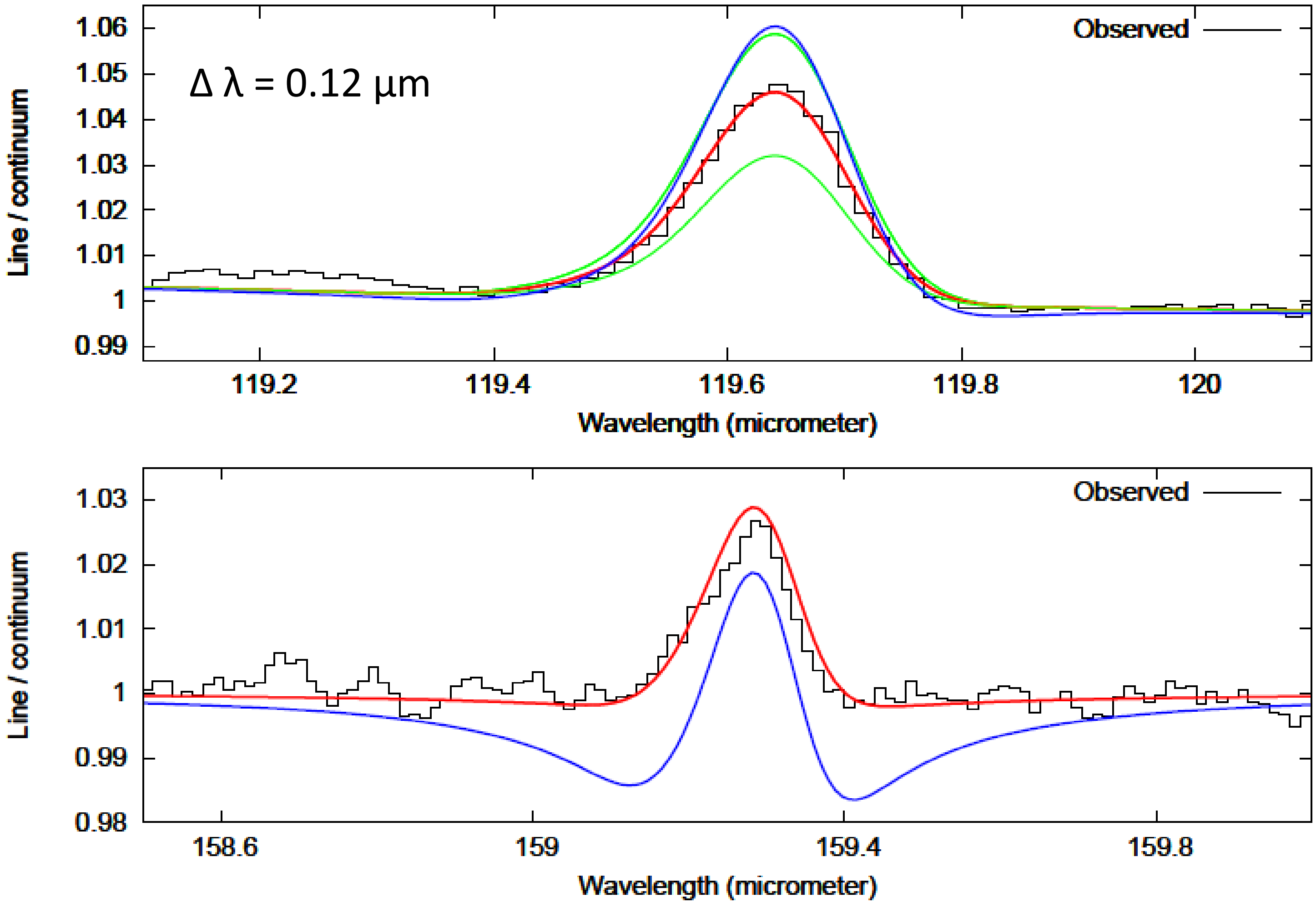
- In Neptune's stratosphere, CH_4 has been difficult to measure (UV, thermal IR)
  - Factor-of-ten range in reported abundances (0.6-5 x 10^{-3}) !

- Yet, methane is a key species, being at the origin of stratospheric hydrocarbon photochemistry

- Furthermore, its stratospheric abundance is meteorologically-constrained, reflecting its partial condensation at the temperature minimum ("cold trap")

- *Herschel has provided a new and accurate measurement of CH_4 in Neptune's stratosphere from the first observation of the methane rotational lines*

CH_4 - PACS



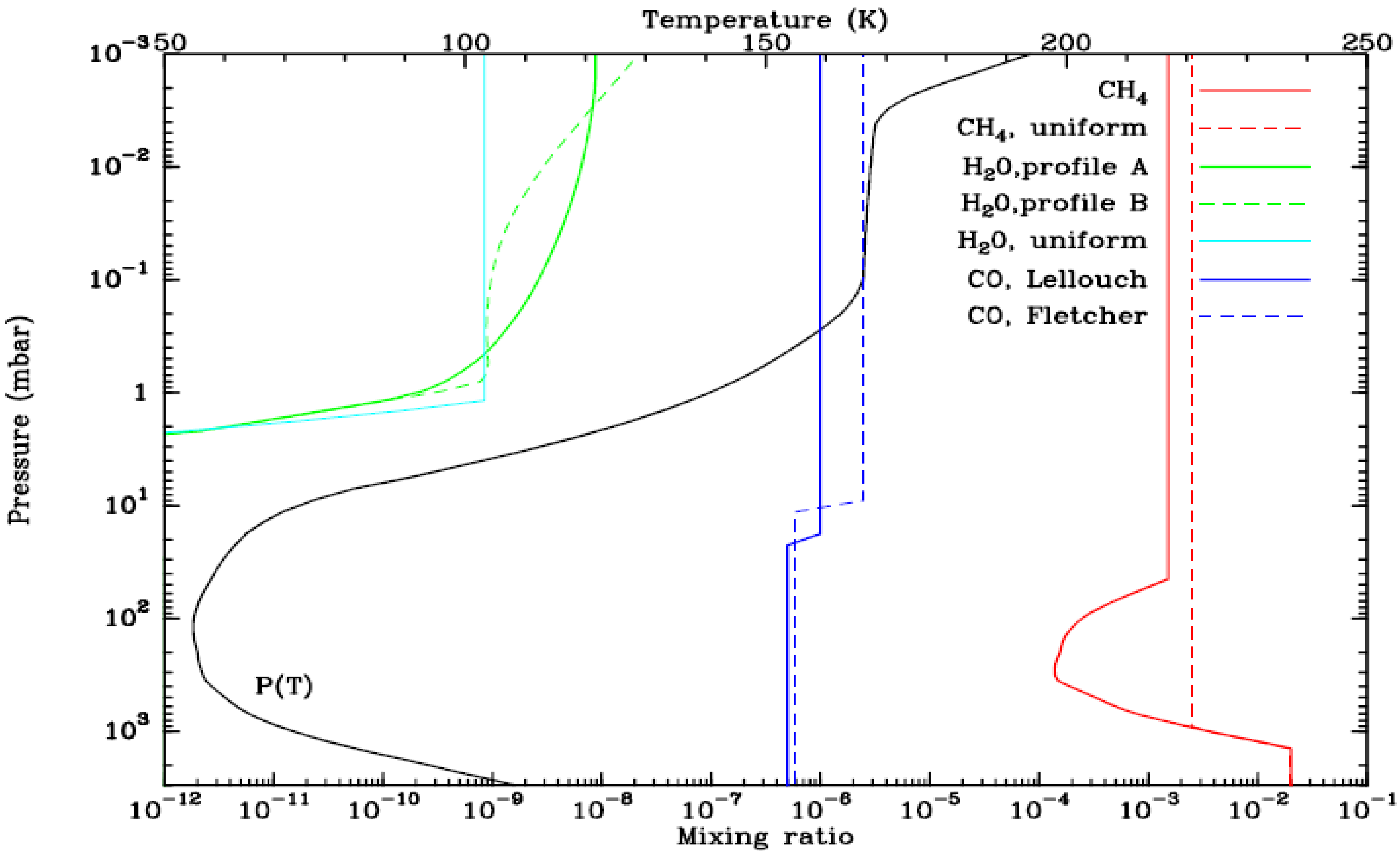
CH_4 (1.5×10^{-3})

CH_4 ($1\text{-}2 \times 10^{-3}$)

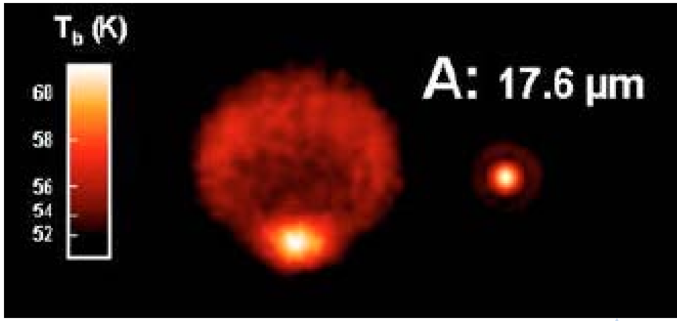
CH_4 (2.5×10^{-3})
Down to 800 mbar

Obs. date: 30 – 31 October 2009

P(T) and Molecular profiles



CH_4 - Results



The retrieved stratospheric methane mixing ratio :

$qCH_4 = 1.5 \pm 0.2 x\ 10^{-3}$

First precise measurement of CH_4 in Neptune's stratosphere

-smaller than the troposphere value (2%) , because of the condensation at the cold trap.

-nevertheless, exceeds the cold trap saturation value by factor 10

Most probable origin of this elevated value : CH_4 leaks from the warmer southern region (i.e. +6K from Orton et al 2007) and is redistributed planetwide by global circulation

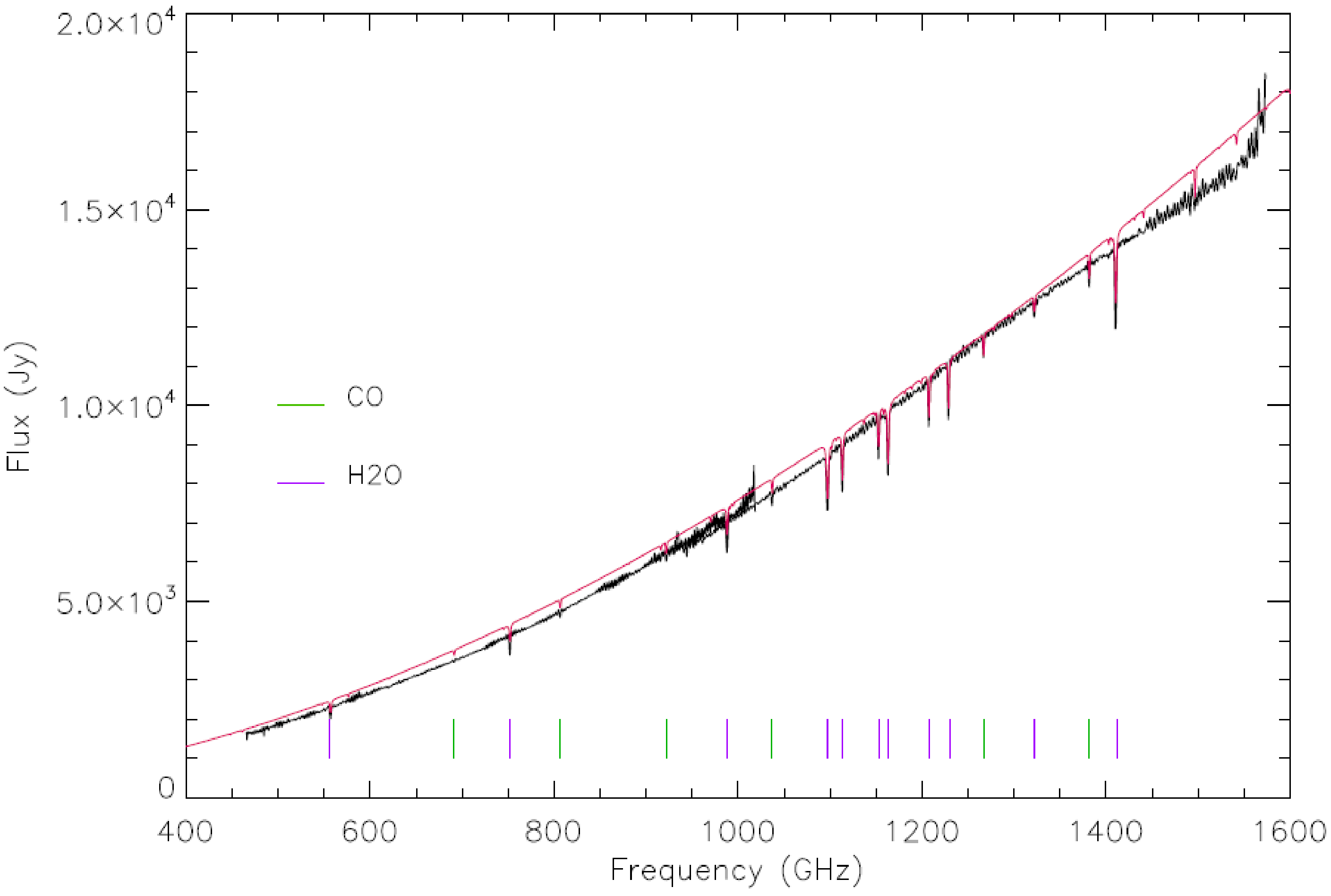
Lellouch et al., 2010, A&A in press

SPIRE Mars observations

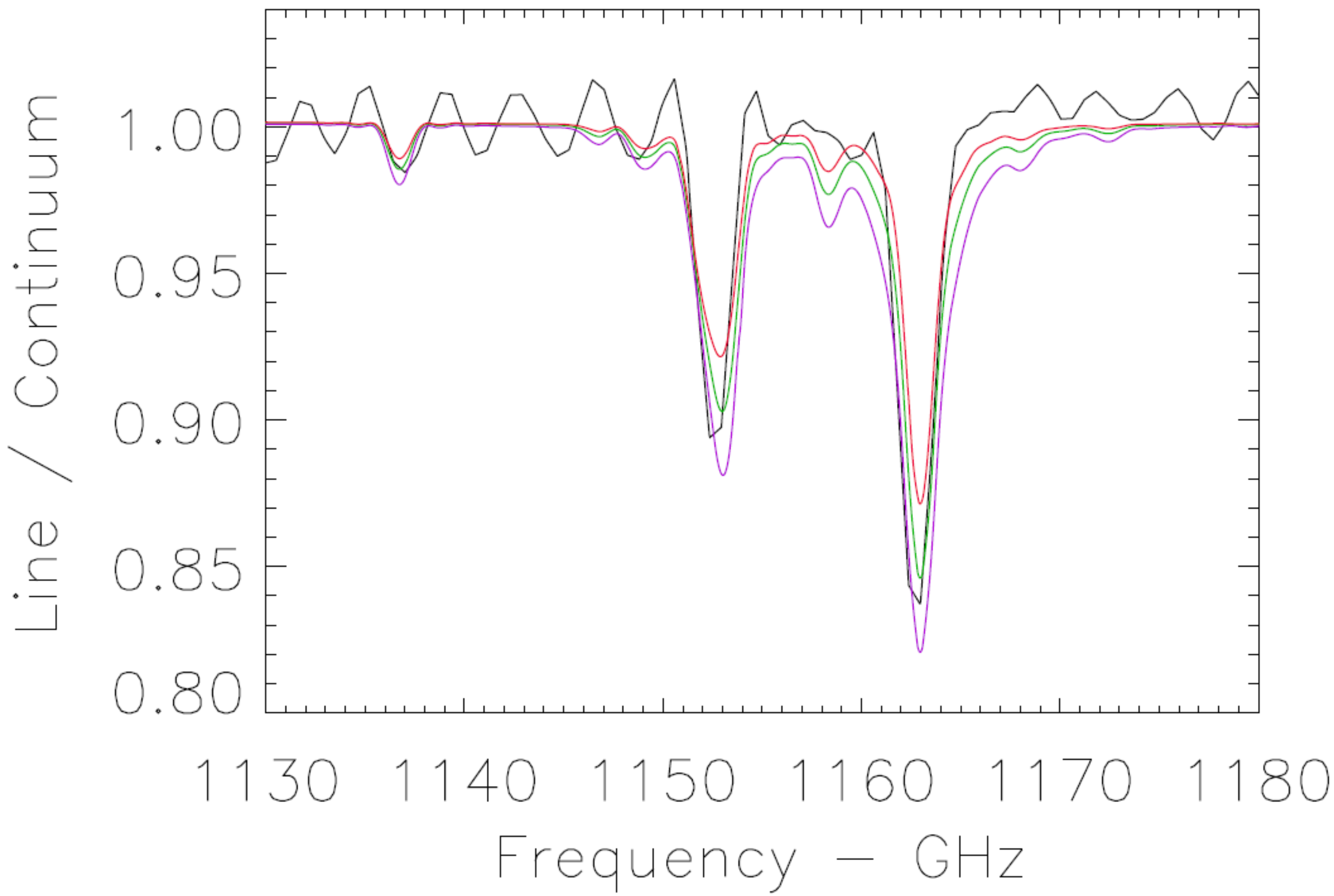
- First continuous disk averaged spectrum from 450 – 1550 GHz
- Performed on 6 November 2009 (OD 176)
- Detection of water and carbon monoxide lines

Line Number	Species	Transition	Frequency (GHz)
1	Ortho H_2O	1_{10}-1_{01}	556.94
2	CO	J=6-5	691.491
3	Para H_2O	2_{11}-2_{02}	752.03
4	CO	J=7-6	806.65
5	CO	J=8-7	921.8
6	Para H_2O	2_{02}-1_{11}	987.93
7	CO	J=9-8	1036.91
8	Ortho H_2O	3_{12}-3_{03}	1097.37
9	Para H_2O	1_{11}-0_{00}	1113.34
10	CO	J=10-9	1152.01*
11	Ortho H_2O	3_{12}-2_{21}	1153.13
12	Ortho H_2O	3_{21}-3_{12}	1162.91
13	Para H_2O	4_{22}-4_{13}	1207.64
14	Para H_2O	2_{20}-2_{11}	1228.79
15	CO	J=11-10	1267.01
16	H_2O	6_{25}-5_{32}	1322.06
17	CO	J=12-11	1382.0
18	H_2O	5_{23}-5_{14}	1410.6

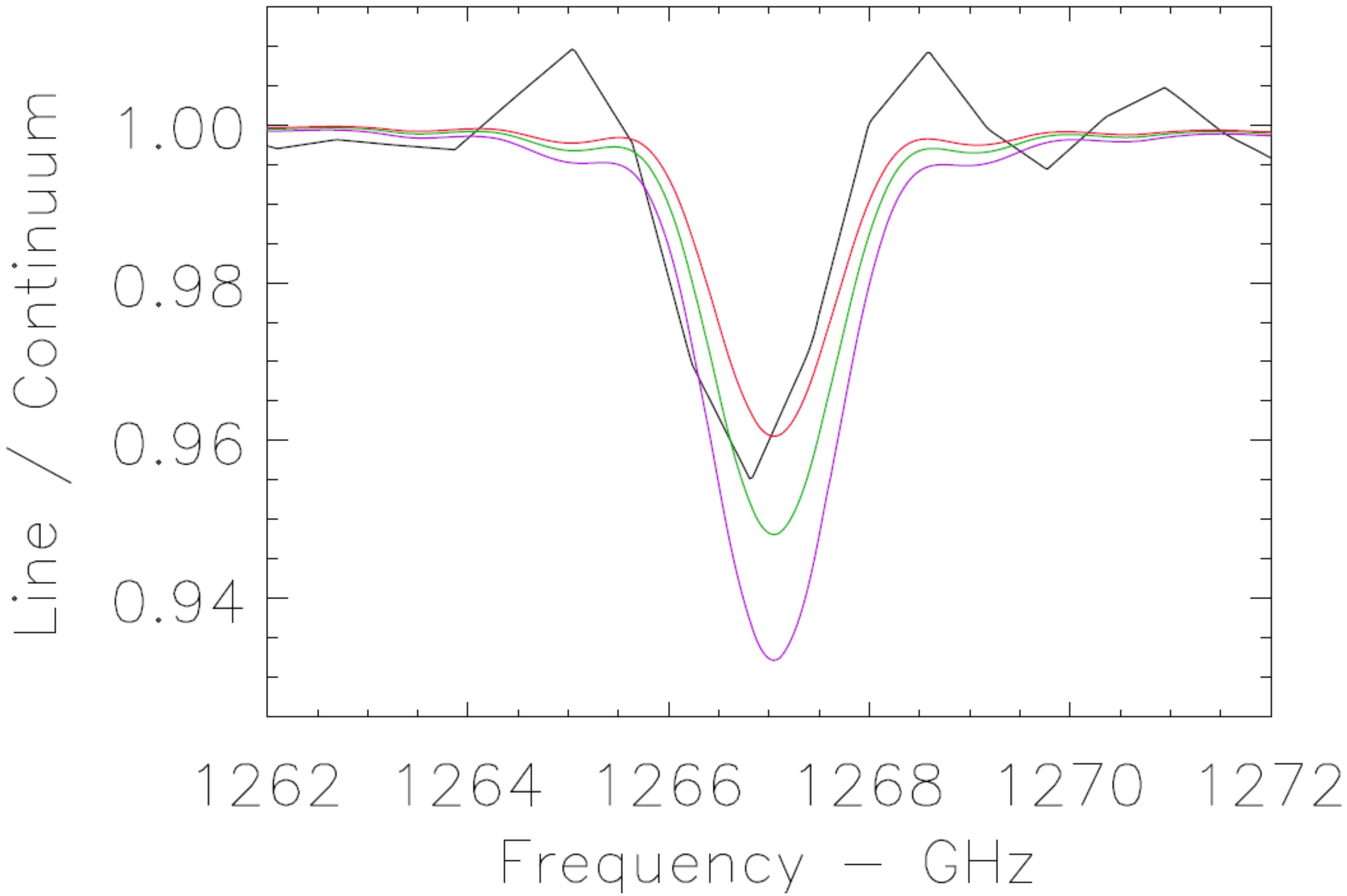
SPIRE spectrum of Mars



Detection of 3_{12}-2_{21} and 3_{21}-3_{12} water lines and 50, 100 and 200 ppm simulations



Detection of CO 11-10 line and simulations for 450, 900 and 1800 ppm



Results SPIRE on Mars

- SPIRE can observe bright sources llike Mars
- First continuous 450 – 1550 GHz spectrum
-
- Water volume mixing ratio best fit: 100 ppm
- Carbon monoxide mixing ratio best fit: 900 ppm

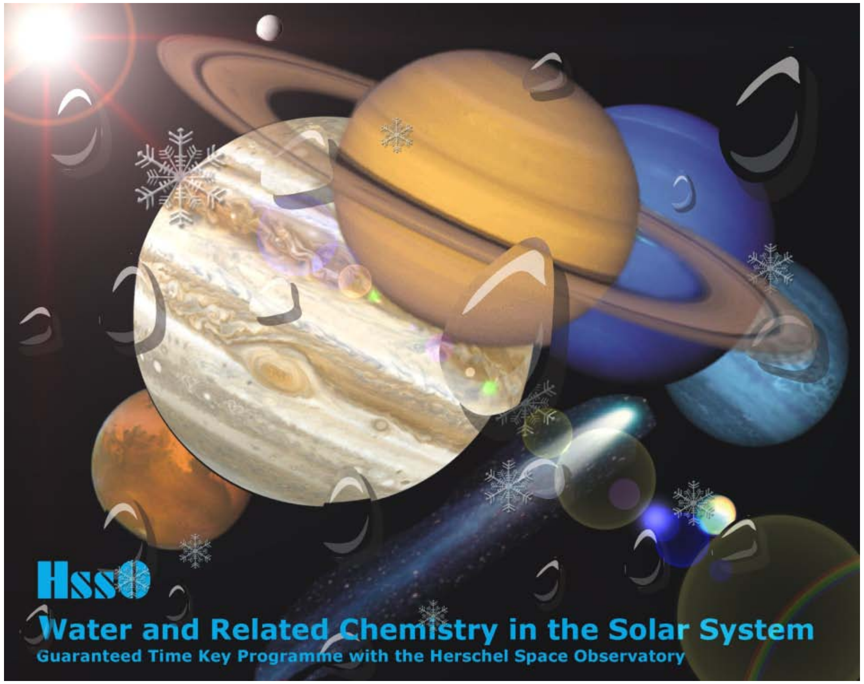
Swinyard et al., 2010, A&A in press

HssO: What next?

- Chemistry in the martian atmosphere
- Extended sources in comets
- Saturn, Titan and its environment
- Source of water in Jupiter‘s and Neptune‘s stratosphere

Visit our HssO web site

- http://www.mps.mpg.de/projects/herschel/HssO/index.htm
- Hartogh et al, 2009. Planetary and Space Science 57, issue 13, 1596-1606.



Additional material

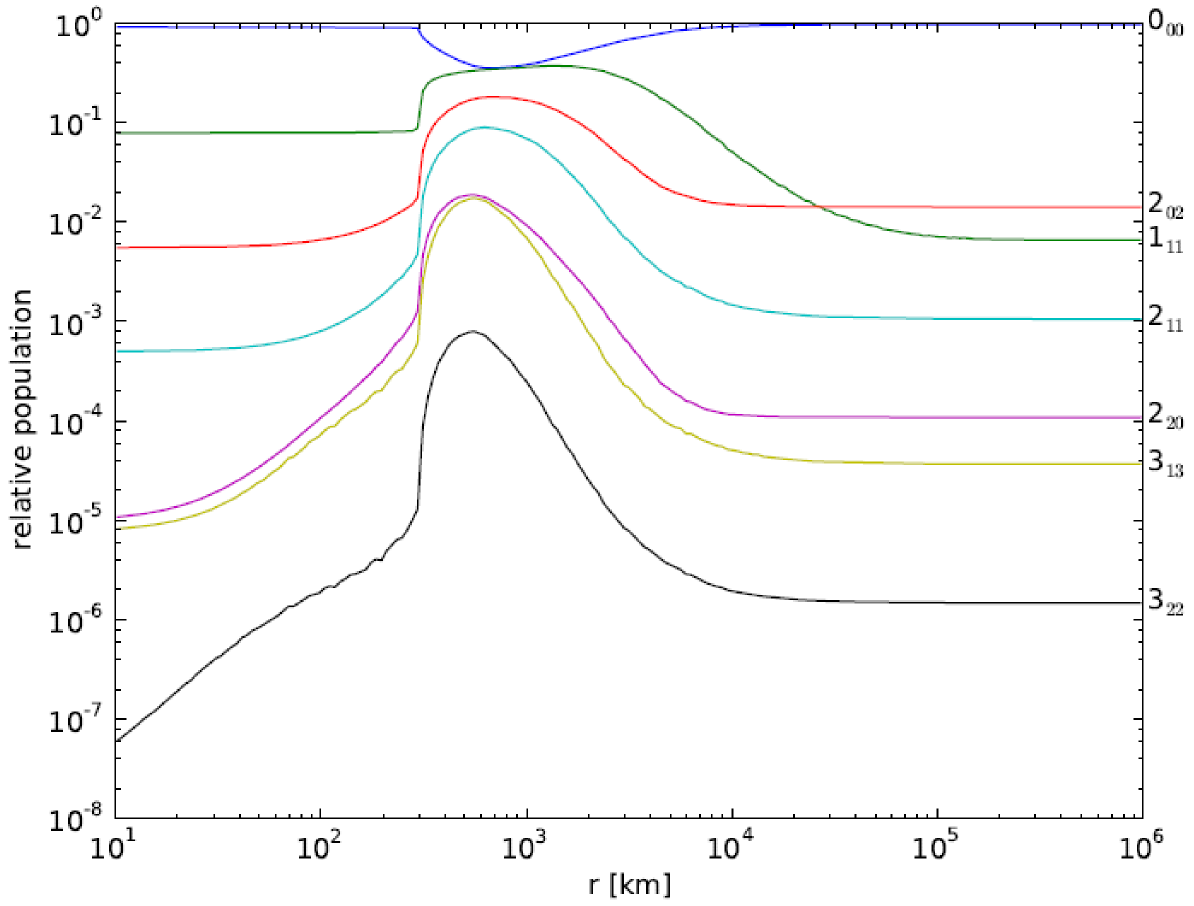
Coma Expansion Velocity

- Self absorption makes the lines asymmetric
- The redshifted side is not opaque. It is used to determine the outgassing velocity.
- It has been determined to be 550 m/s.

Line excitation mechanisms

- Water-water collisions dominate in inner coma
- Infrared fluorescence by solar radiation and water electron collisions contribute to the detected emissions from the outer coma

Level populations of para water



Modeling the line shape

- Two methods:
  - Accelerated Monte Carlo radioative transfer (Hogerheijde & van der Tak, 2000; Bensch & Bergin 2004)
  - Sobolev escape probability method (Bockeleé-Morvan 1987; Biver 1997).
- Results very similar (within 5 %)

Model Inputs

- Gas density profile: Haser model
- Expansion velocity and neutral gas kinetic temperature constant in coma
- Ortho-to-para water abundance ratio: 3 (Crovisier et al, 1998).
- Molecular data from LAMDA (Schöier et al. 2005)
- Electron densitiy profile from 1P/Halley according to Biver (1997)
- Electron density profile scaled to C/2008 Q3
- Xne is a free scaling parameter in the model, derived from radial brightness distribution (Biver, 2007)
- MC-code: water-electron collisions from Faure et al. (2004)
- IR pumping rates (solar radiation) from Zakharov et al, (2007)