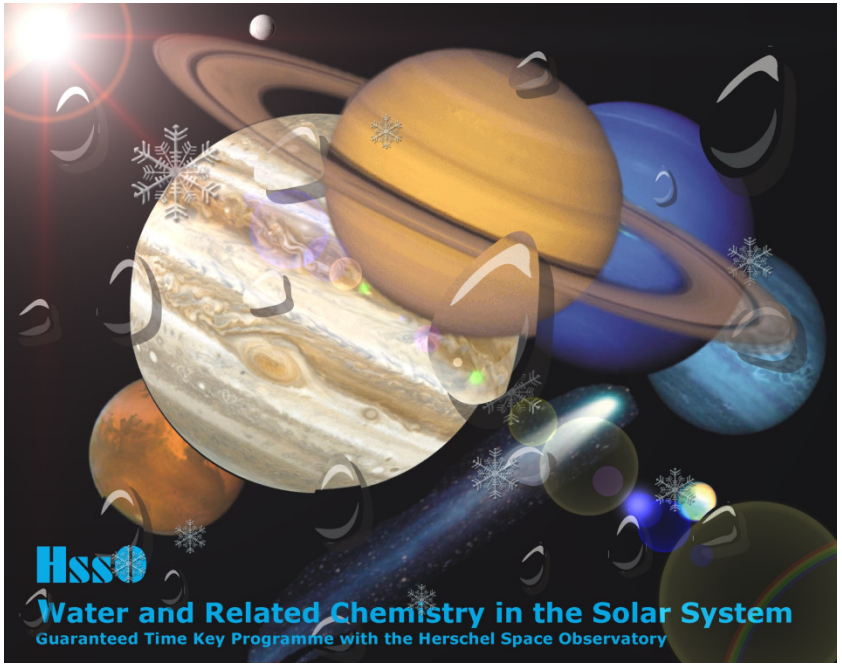
Water and related chemistry in the solar system (HssO) – initial results



Paul Hartogh, Jacques Crovisier, Emmanuel Lellouch, Nicolas Biver, Dominique Bockelée-Morvan, Helmut Feuchtgruber, Trevor Fulton, Matt Griffin, Christopher Jarchow, Raphael Moreno, Miriam Rengel, Bruce Swinyard, Bart Vandenbussche and the HssO Team

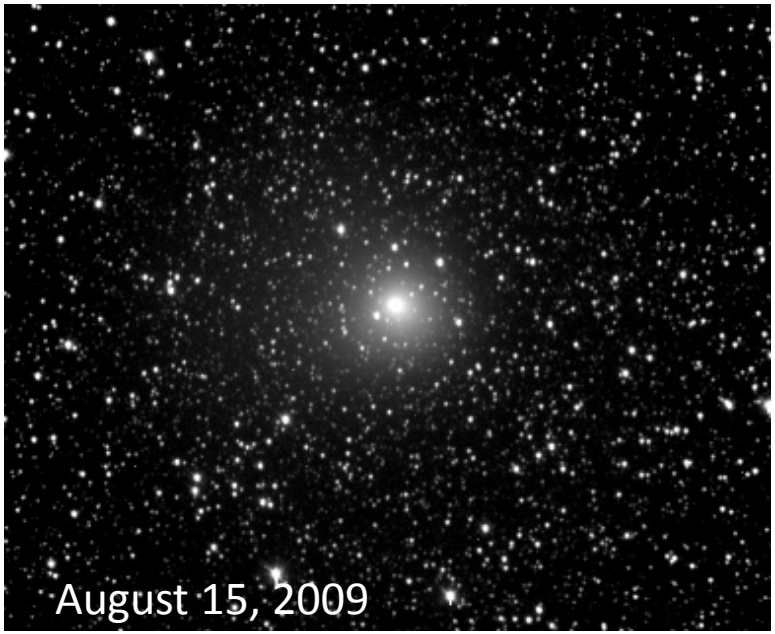
HssO Participants

- *Marek Banaszkiewicz,*
- *Frank Bensch*
- *Edwin A. Bergin*
- *Francoise Billebaud*
- *Nicolas Biver[5]*
- *Geoffrey A. Blake*
- *Maria I. Blecka*
- *Joris Blommaert*
- *Dominique Bockelée-Morvan*
- *Thibault Cavalié*
- *José Cernicharo*
- *Régis Courtin*
- *Jacques Crovisier*
- *Gary Davis*
- *Leen Decin*
- *Martin Emprechtinger*
- *Pierre Encrenaz*
- *Thérese Encrenaz*
- *Trevor Fulton*
- *Thijs de Graauw*
- *Armando Gonzalez*
- *Paul Hartogh (PI, coordinator)*
- *Damien Hutsemékers*
- *Christopher Jarchow*
- *Emmanuël Jehin*
- *Mark Kidger*
- *Michael Küppers*
- *Arno de Lange*
- *Luisa-Maria Lara*
- *Sarah Leeks*
- *Emmanuel Lellouch*
- *Dariusz C. Lis*
- *Rosario Lorente*
- *Jean Manfroid*
- *Alexander S. Medvedev*
- *Raphael Moreno*
- *David Naylor*
- *Glenn Orton*
- *Ganna Portyankina*
- *Miriam Rengel*
- *Hideo Sagawa*
- *Miguel Sánches-Portal*
- *Rudolf Schieder*
- *Sunil Sidher*
- *Daphne Stam*
- *Bruce Swinyard*
- *Slawomira Szutowicz*
- *Gillian Thornhill*
- *Nicolas Thomas*
- *Miguel de Val Borro*
- *Bart Vandenbussche*
- *Eva Verdugo*
- *Christoffel Waelkens*
- *Helen Walker*

Outline

- Comet C/2006 W3 Christensen PACS/SPIRE
- Neptune methane with PACS
- Mars CO, Water and Isotopes 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

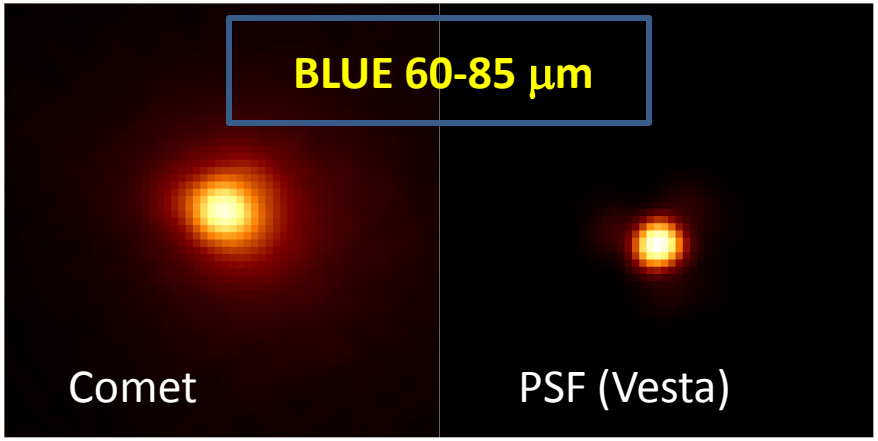
Observations of C/2006 W3 (Christensen) with the Herschel Space telescope

- 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. 2008)
  - High resolution spectral scan, sparse image sampling

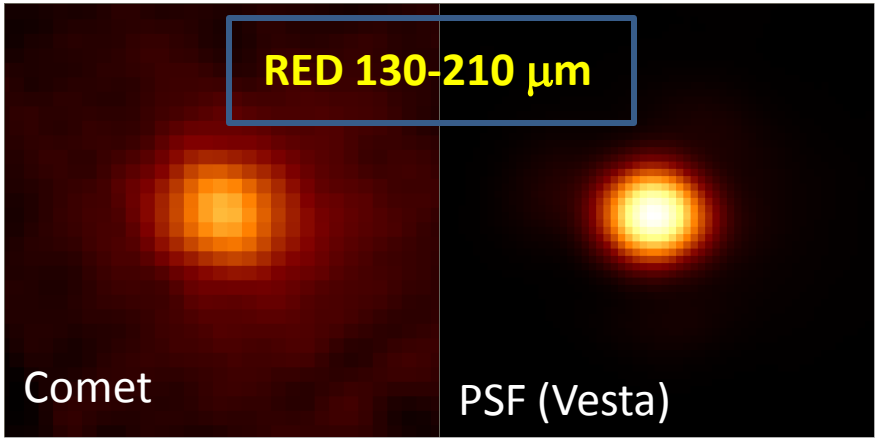
Comet imaging with PACS

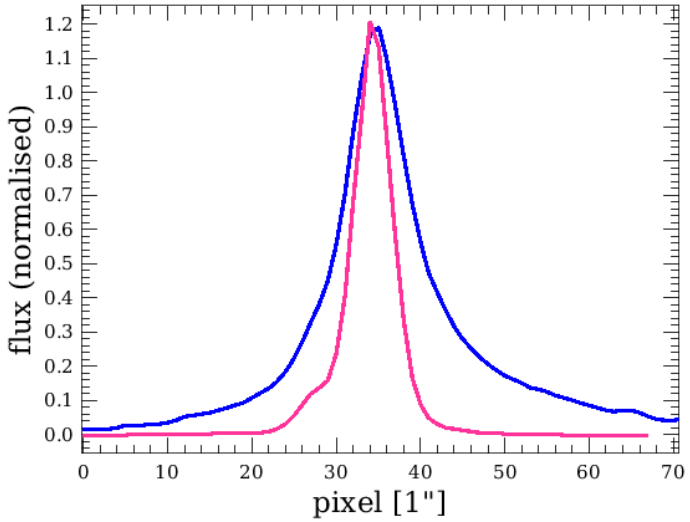
The dust coma is resolved

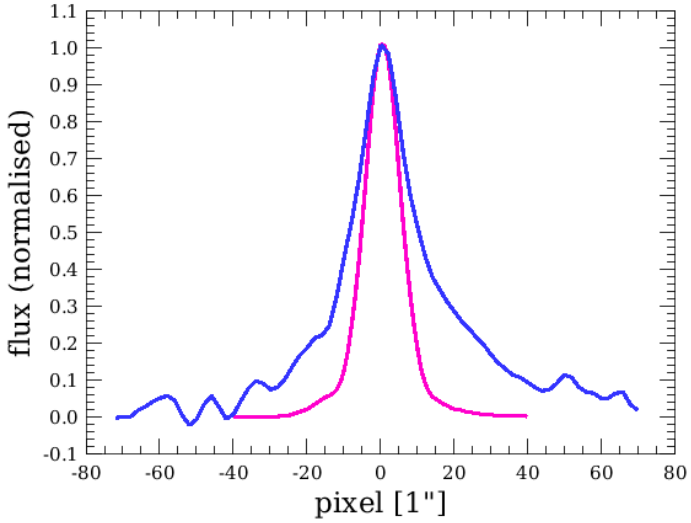
1’ x 1’ (1’=1.6 x10^5 km)



1’ x 1’

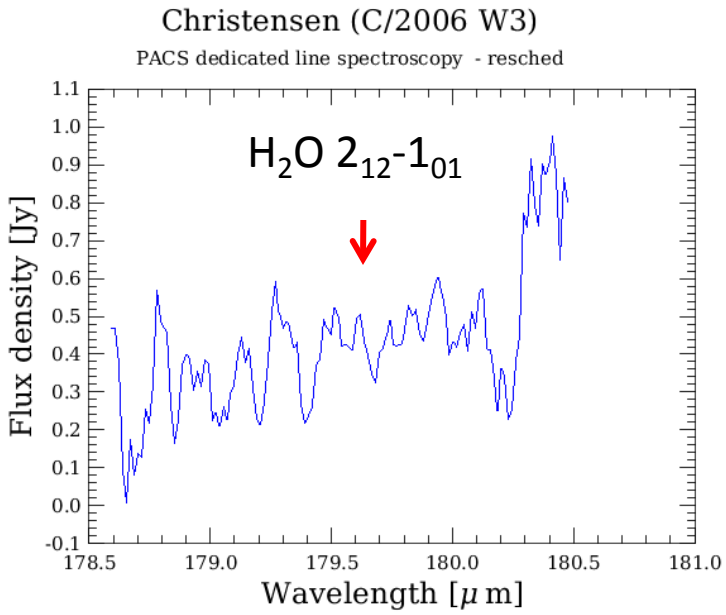


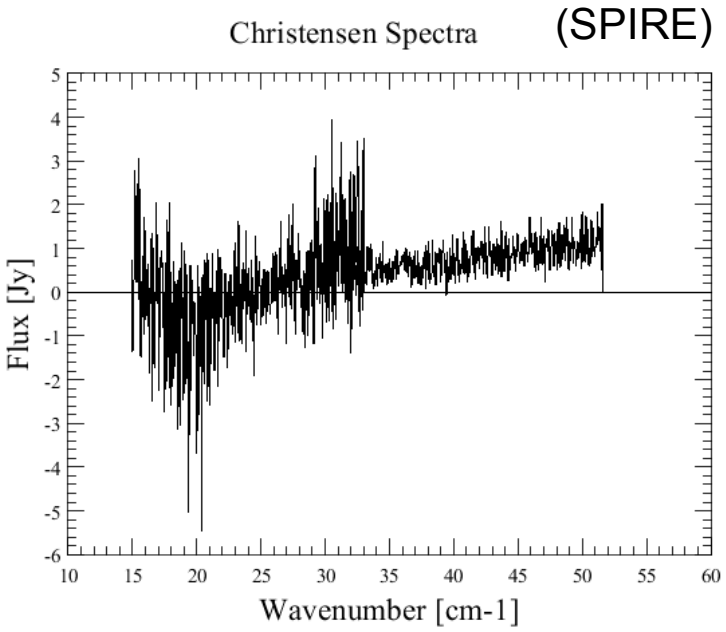




Spectroscopy with PACS and SPIRE

H_2O lines are not detected



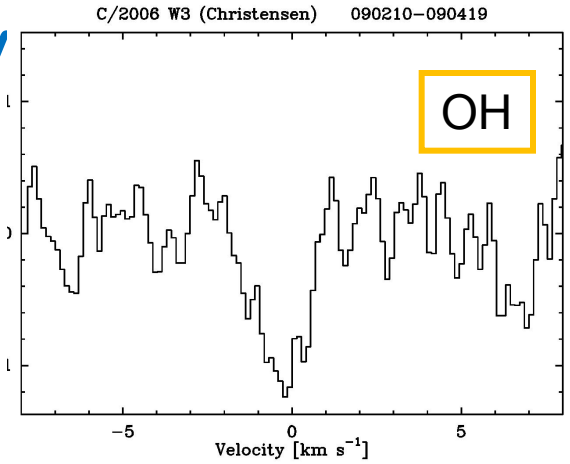


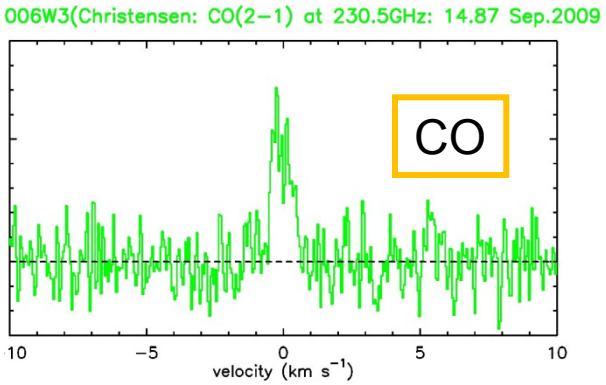
- PACS : Expected strongest H_2O line : 2_{12}-1_{01} @179.65 μm = 1669.9 GHz
- SPIRE: Expected strongest H_2O line : 1_{11}-0_{00} @37.1 cm^{-1} = 1113 GHz
- Excitation and radiative transfer modelling with a coma temperature of 18 K
- 3-sigma upper limits on the water production rate :

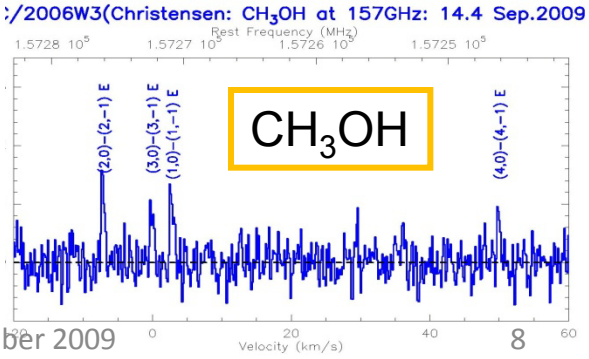
PACS: $Q(H_2O) < 1.2 \times 10^{28}$ mol/s SPIRE: $Q(H_2O) < 6 \times 10^{28}$ mol/s

Supporting observations at Nançay and IRAM

- 2-Jan.-2009 → 19 Apr. 2009: OH radical at Nançay
  r_h = 3.60-3.20 AU: Q_{H2O} = 5 1 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

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

- ✓ Nucleus radius < 6 km (assuming slow rotator)
- ✓ Dust production rate : ~3000 kg/s (assuming β-Pic dust opacities)
- ✓ Dust-to-gas ratio ~ 2 (rough estimate)

Methane in the atmosphere 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

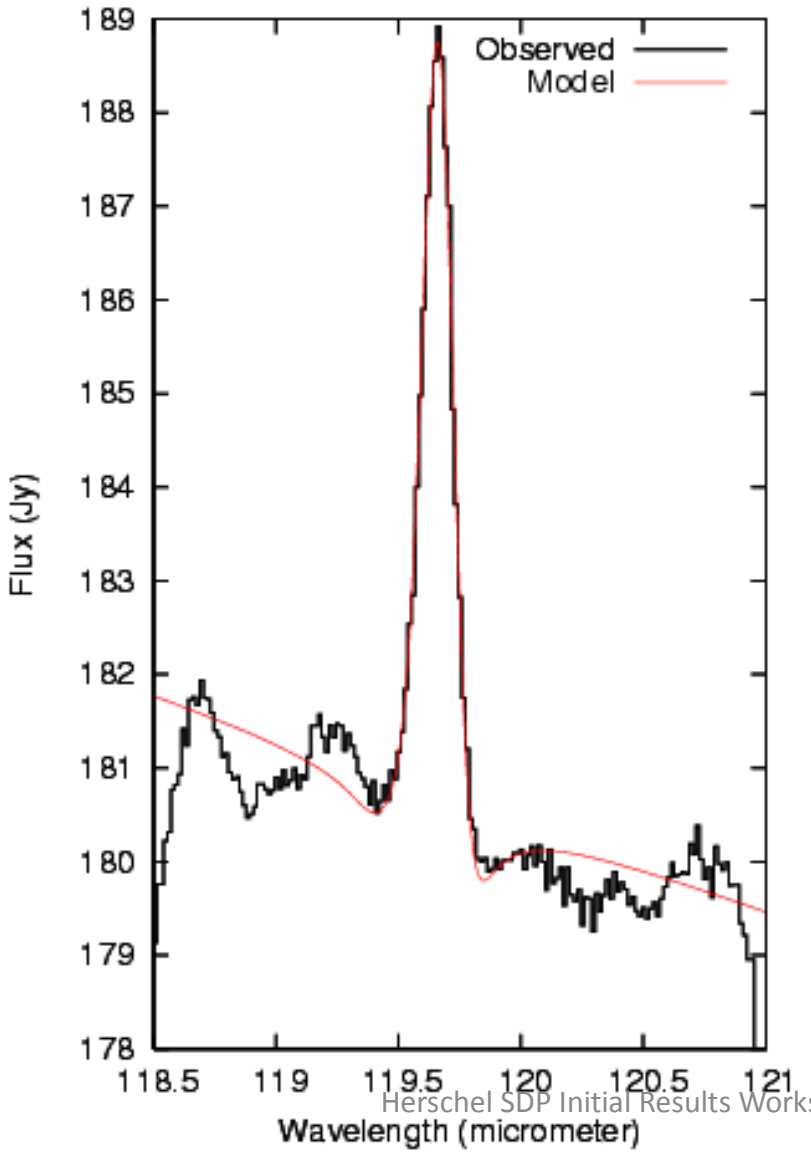
- In Neptune's stratosphere, CH_4 has been difficult to measure (UV, thermal IR)
  - Factor-of-ten range in reported abundances (0.6-5 x 10^{-3}) !

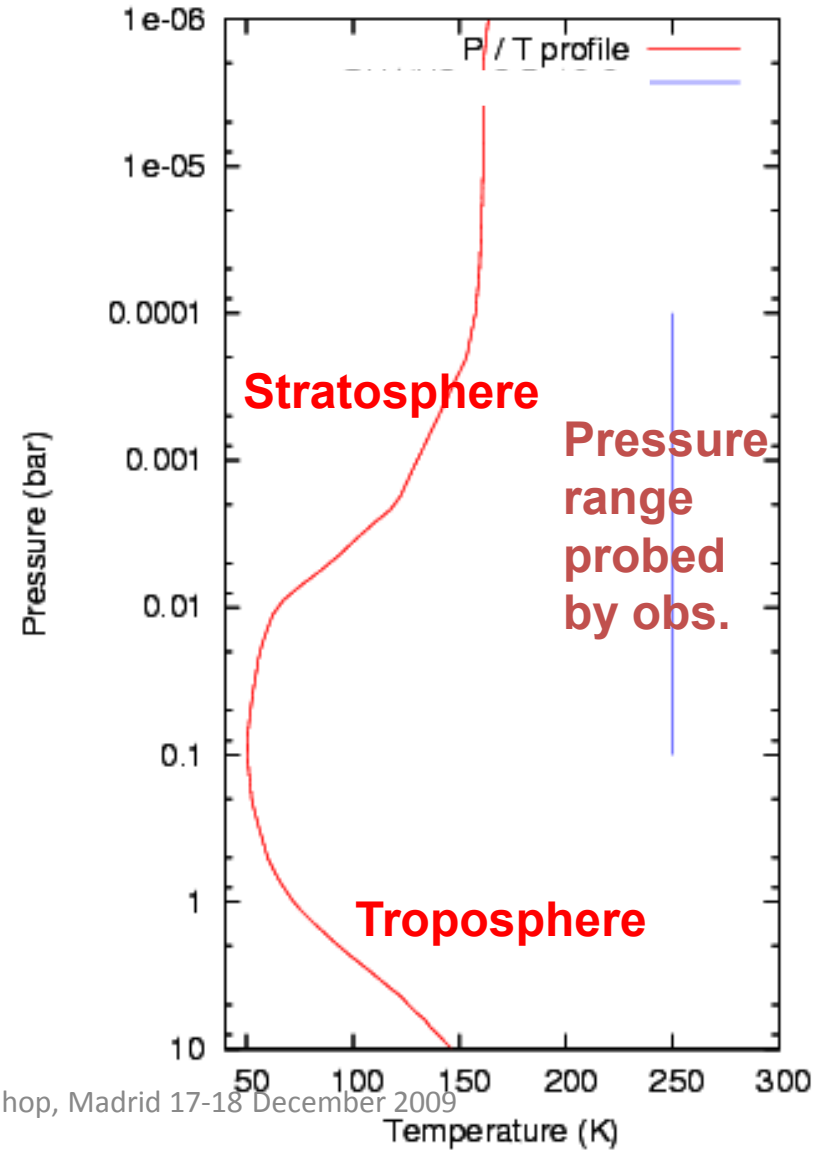
- Yet, methane is a key species, being at the origin of stratospheric hydrocarbon photochemistry

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

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

First detection of methane 120 micron line on Neptune with PACS





Before looking at the PACS and SPIRE data of Mars it may be interesting to remember:

William Herschel offered the first scientific evidence that Mars might have an atmosphere. His observations of the planet in 1783 led him to suppose that some changes he had noted were due to "clouds and vapors.„

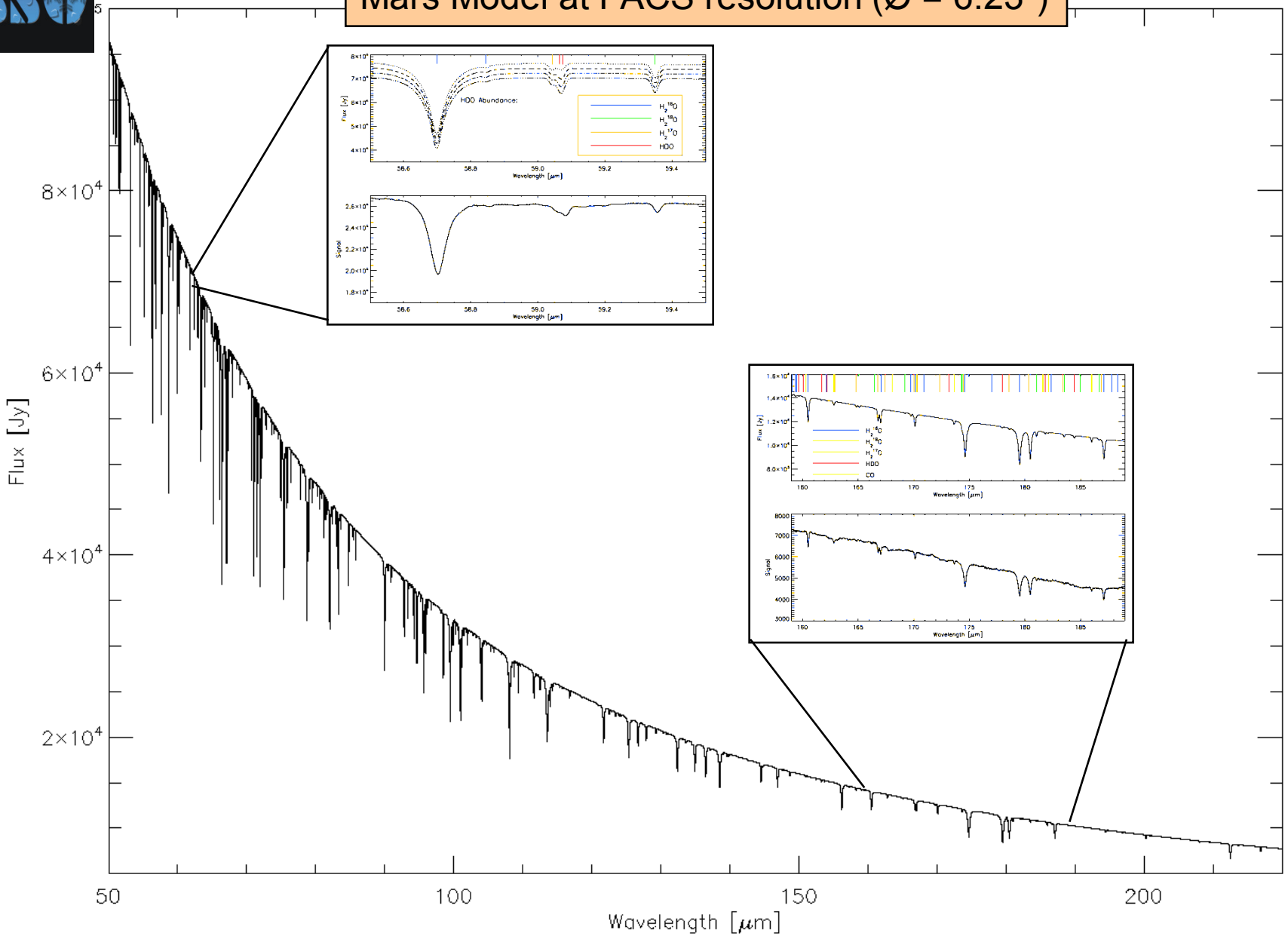
[Herschel, W., "On the Remarkable Appearances at the Polar Regions of the Planet Mars, the Inclination of its Axis, the Position of its Poles, and its spheroidal Figure; with a few Hints relating to its real Diameter and Atmosphere." *Philosophical Transactions of the Royal Society of London*, **74**, 233 (1784).]

Actually the last sentence in the conclusions section of this paper “Result of the contents of this paper” says:

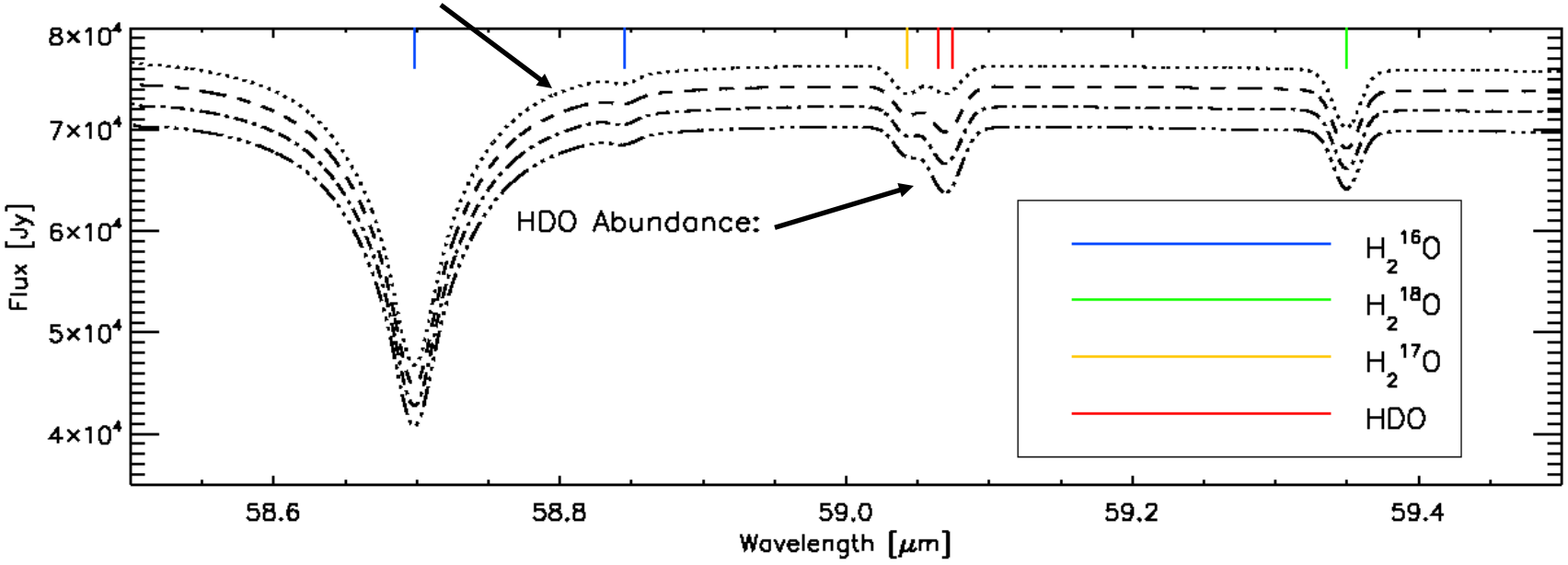
……
……
“And the planet has a considerable but moderate atmosphere, so that its inhabitants probably enjoy a situation in many respects similar to ours.”

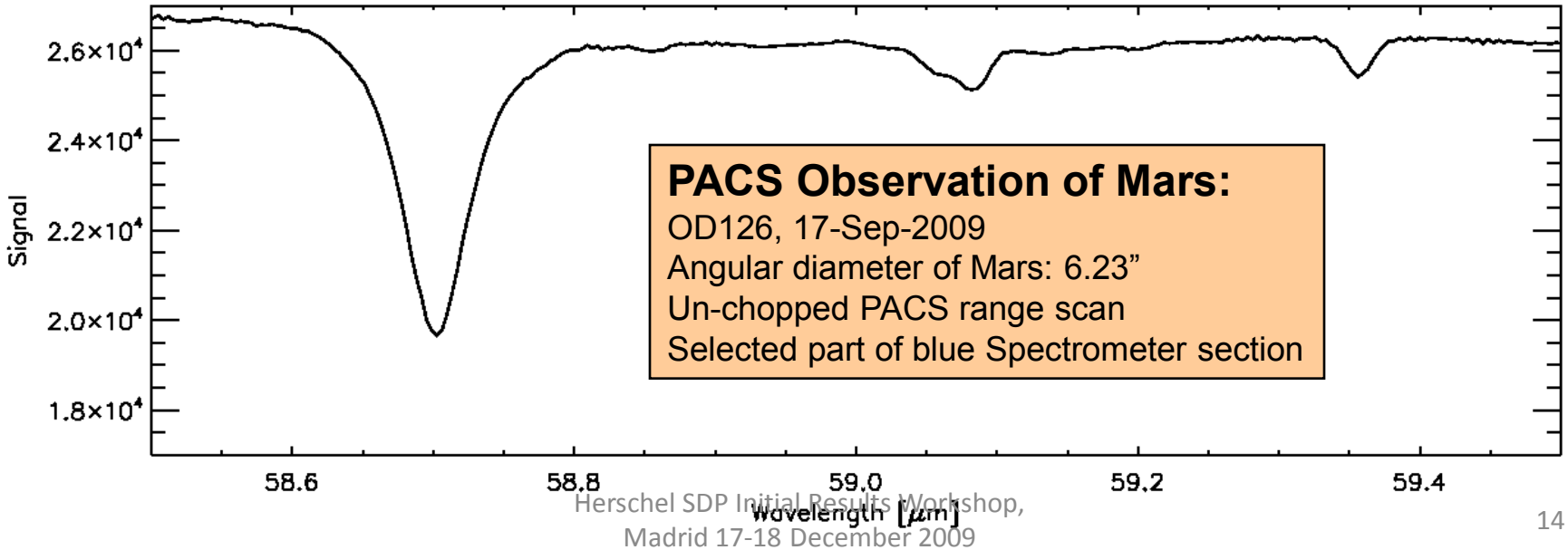
W. Herschel

Mars Model at PACS resolution (Ø = 6.23”)

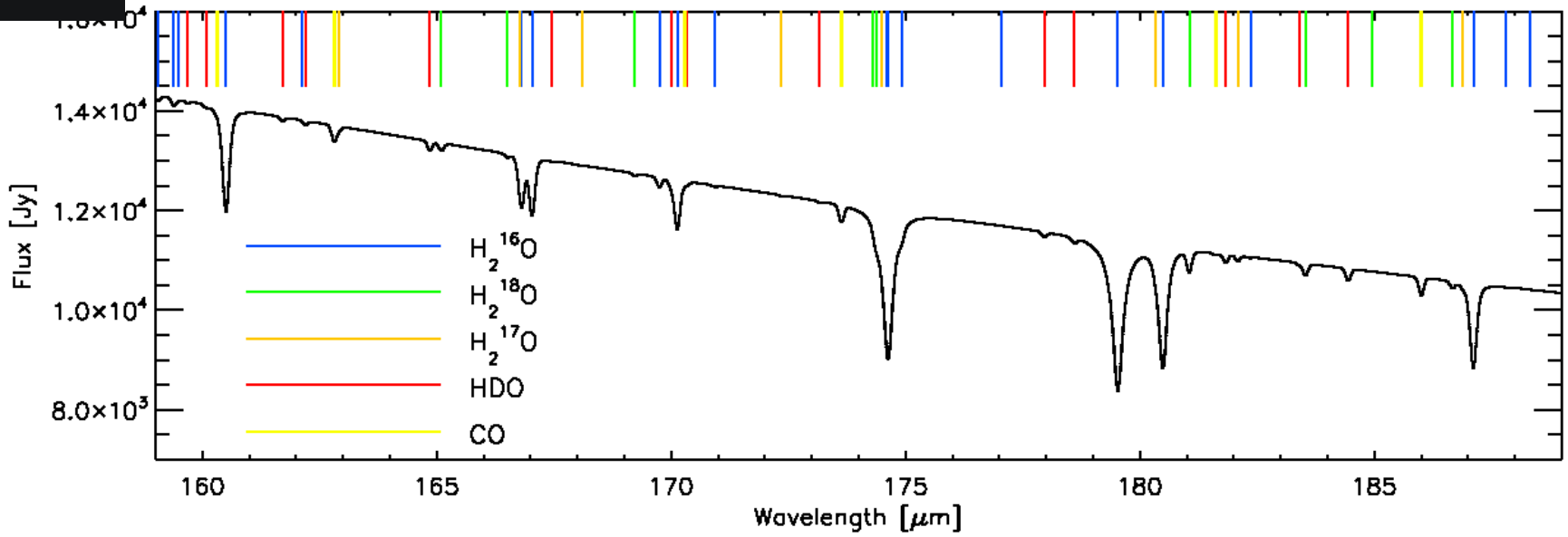


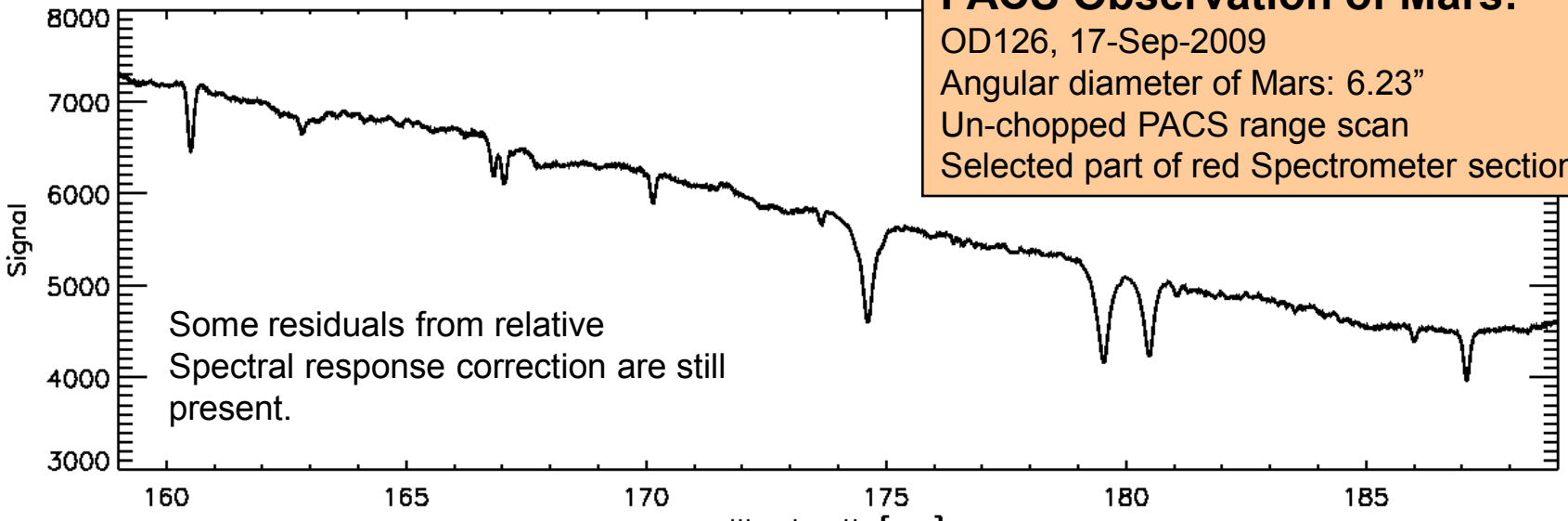
Different Models are offset for clarity





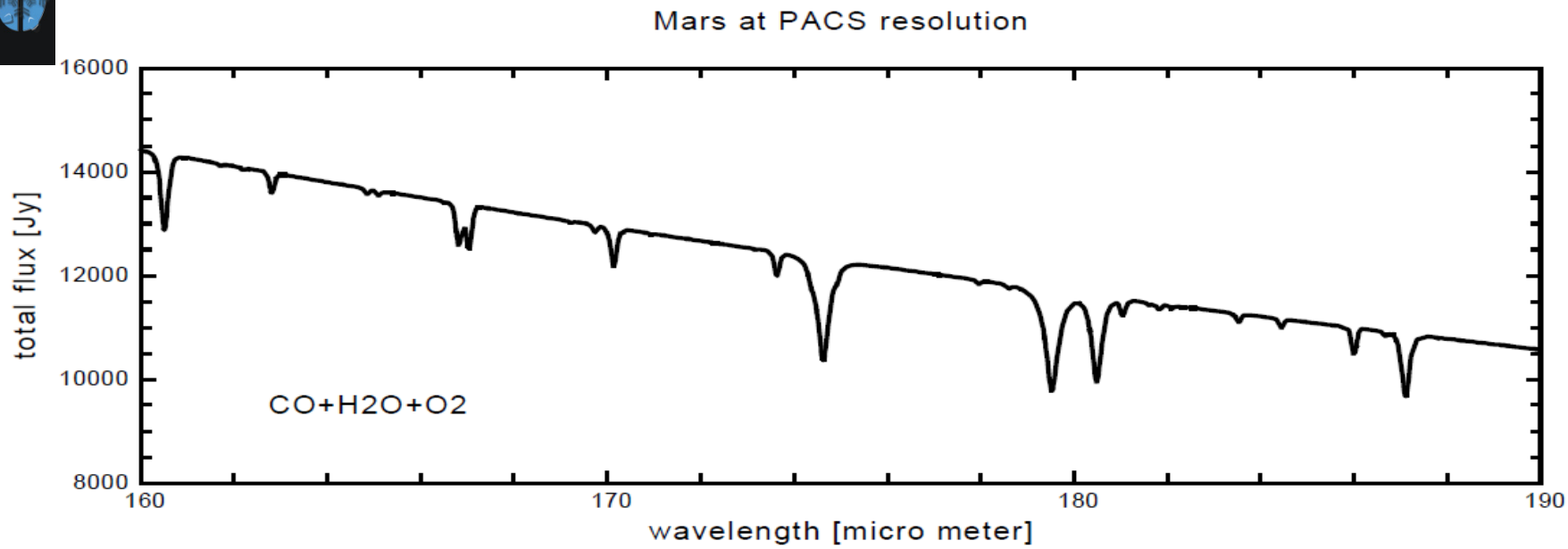
PACS Observation of Mars:
OD126, 17-Sep-2009
Angular diameter of Mars: 6.23”
Un-chopped PACS range scan
Selected part of blue Spectrometer section

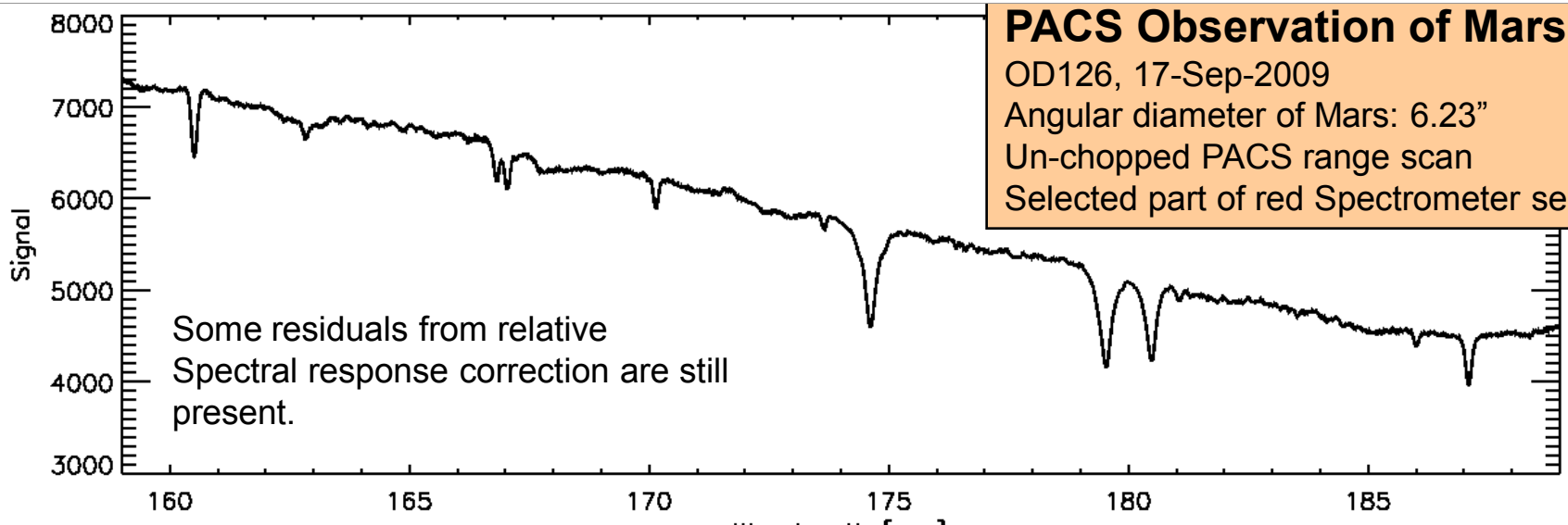




PACS Observation of Mars:
OD126, 17-Sep-2009
Angular diameter of Mars: 6.23”
Un-chopped PACS range scan
Selected part of red Spectrometer section

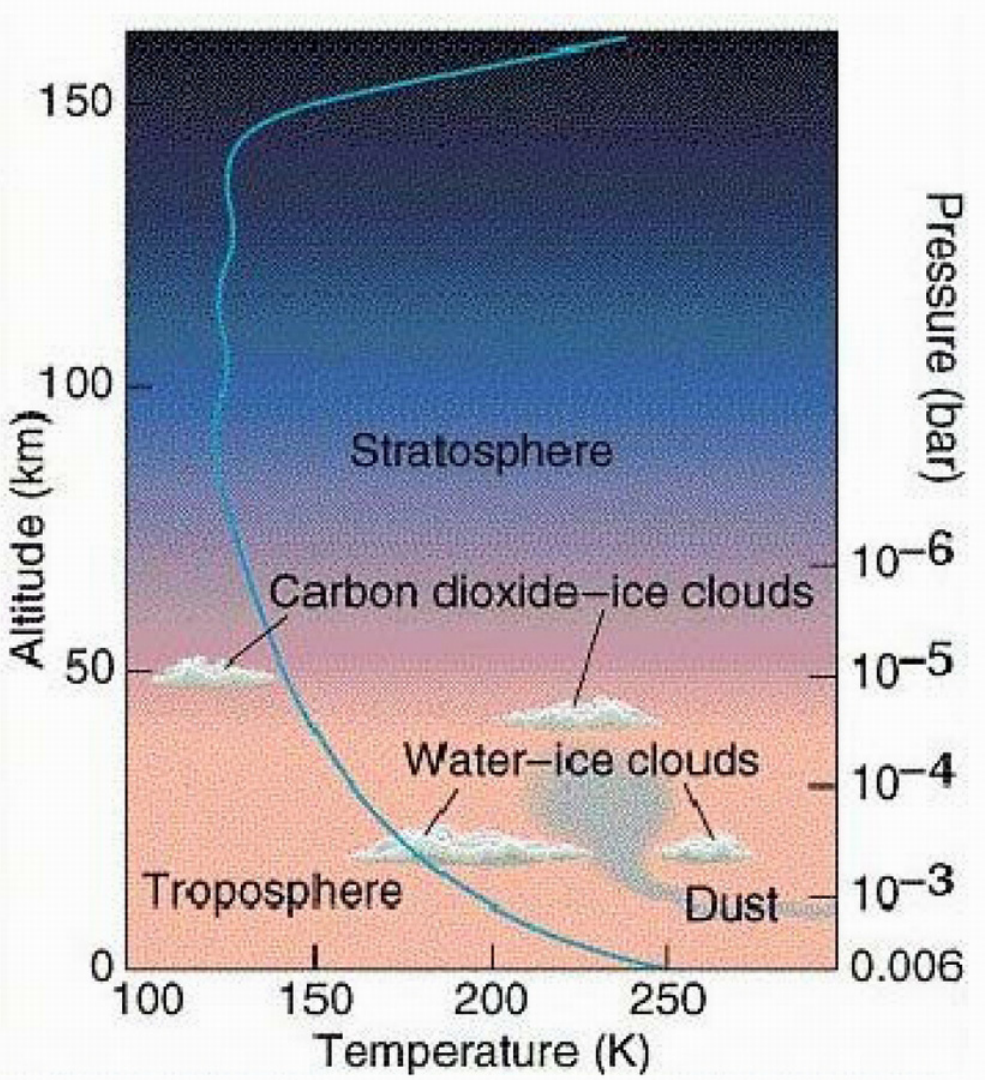
Some residuals from relative Spectral response correction are still present.





PACS Observation of Mars:
OD126, 17-Sep-2009
Angular diameter of Mars: 6.23”
Un-chopped PACS range scan
Selected part of red Spectrometer section

Some residuals from relative Spectral response correction are still present.

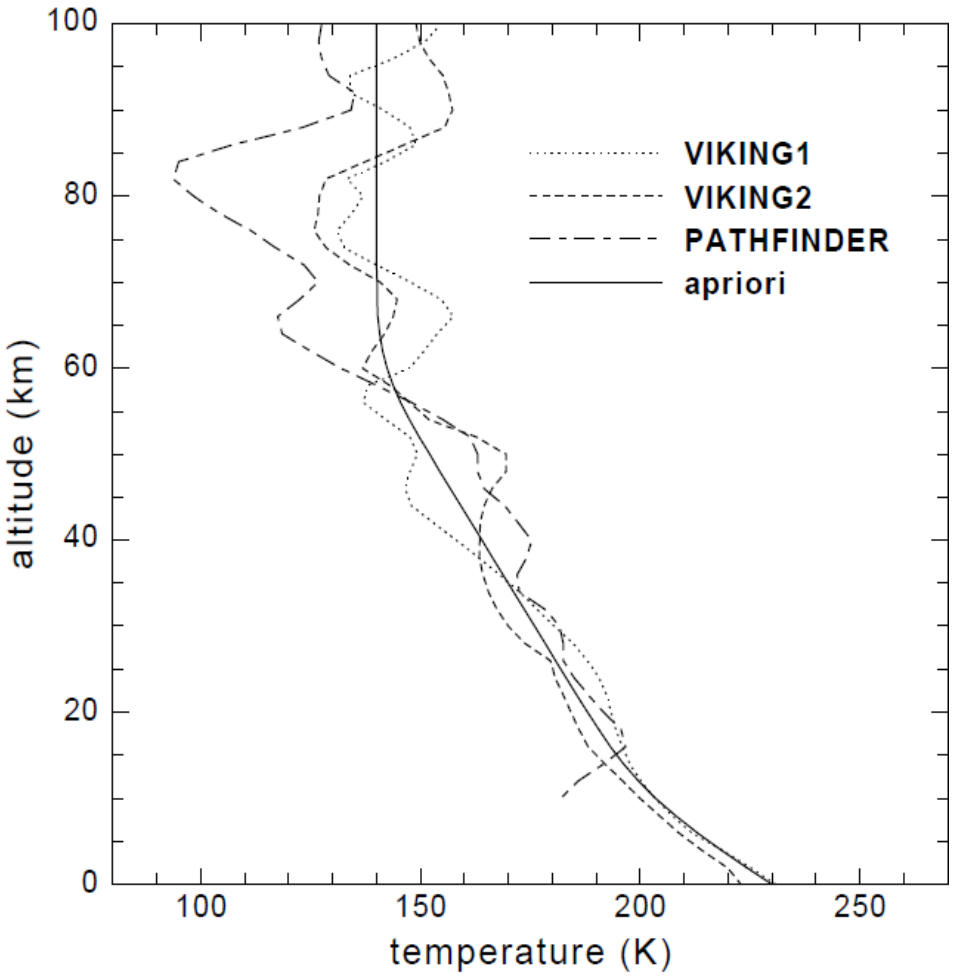


Model Description:

- Thermal Profile (see figure)
- Uniform mixing of all atmospheric species:
  - Carbon dioxide 95.32%
  - Nitrogen 2.7%
  - Argon 1.6%
  - Oxygen 0.13%
  - Carbon monoxide 0.07%
  - Water vapor 0.03%
  - Methane 10.5 ppb

Radiative Transfer Code:

- Multi-layer (50 pressure levels), line by line code
- Line parameters from HITRAN database
- Mars Continuum Emission Model Tool, by Rudy, D.J., et al. 1987, Icarus, 71, 159
- High resolution model spectra convolved to PACS resolution



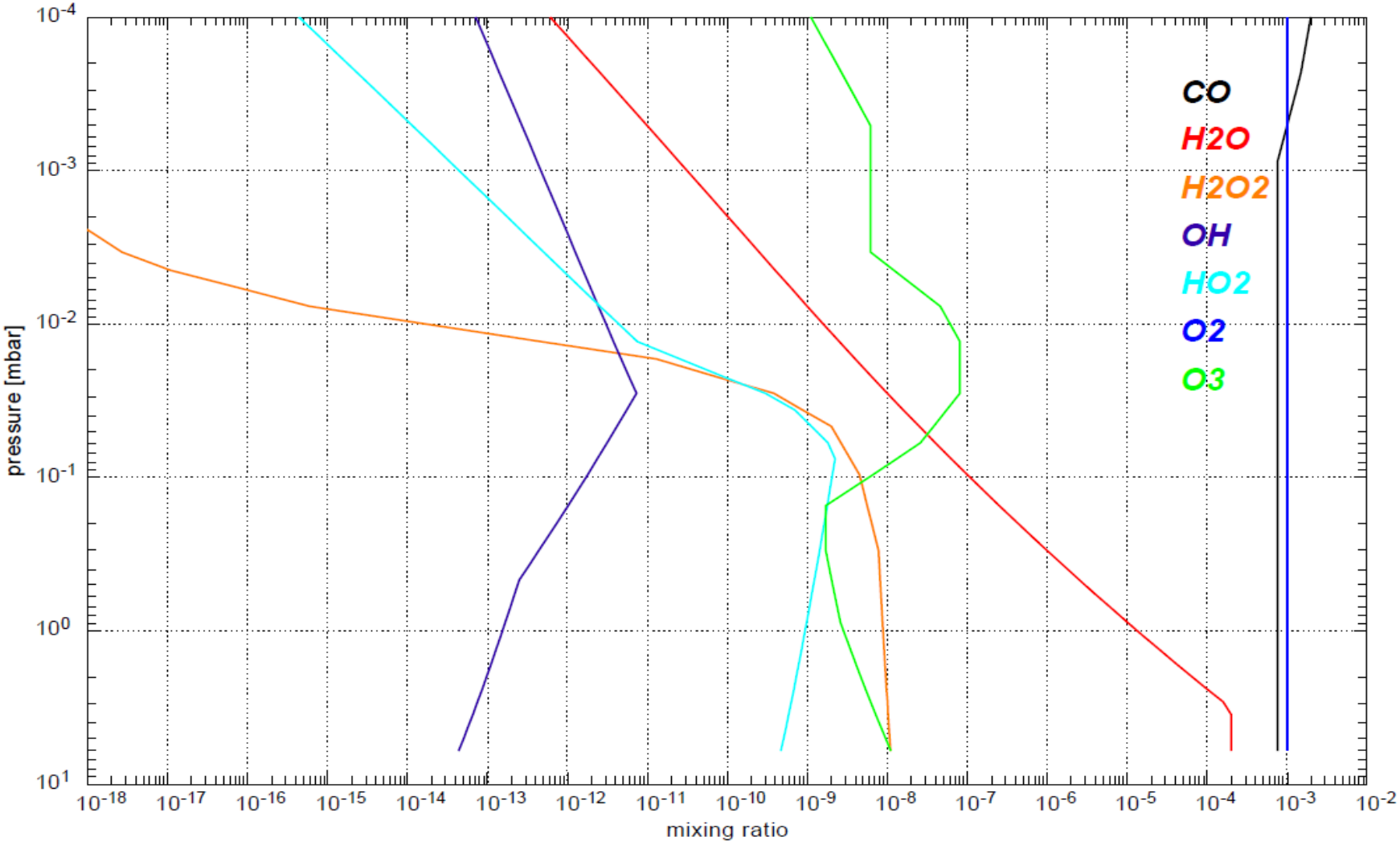
Model Description:

- Thermal Profile (see figure)
- Uniform mixing of all atmospheric species:
  - Carbon dioxide 95.32%
  - Nitrogen 2.7%
  - Argon 1.6%
  - Oxygen 0.13%
  - Carbon monoxide 0.08%

Radiative Transfer Code:

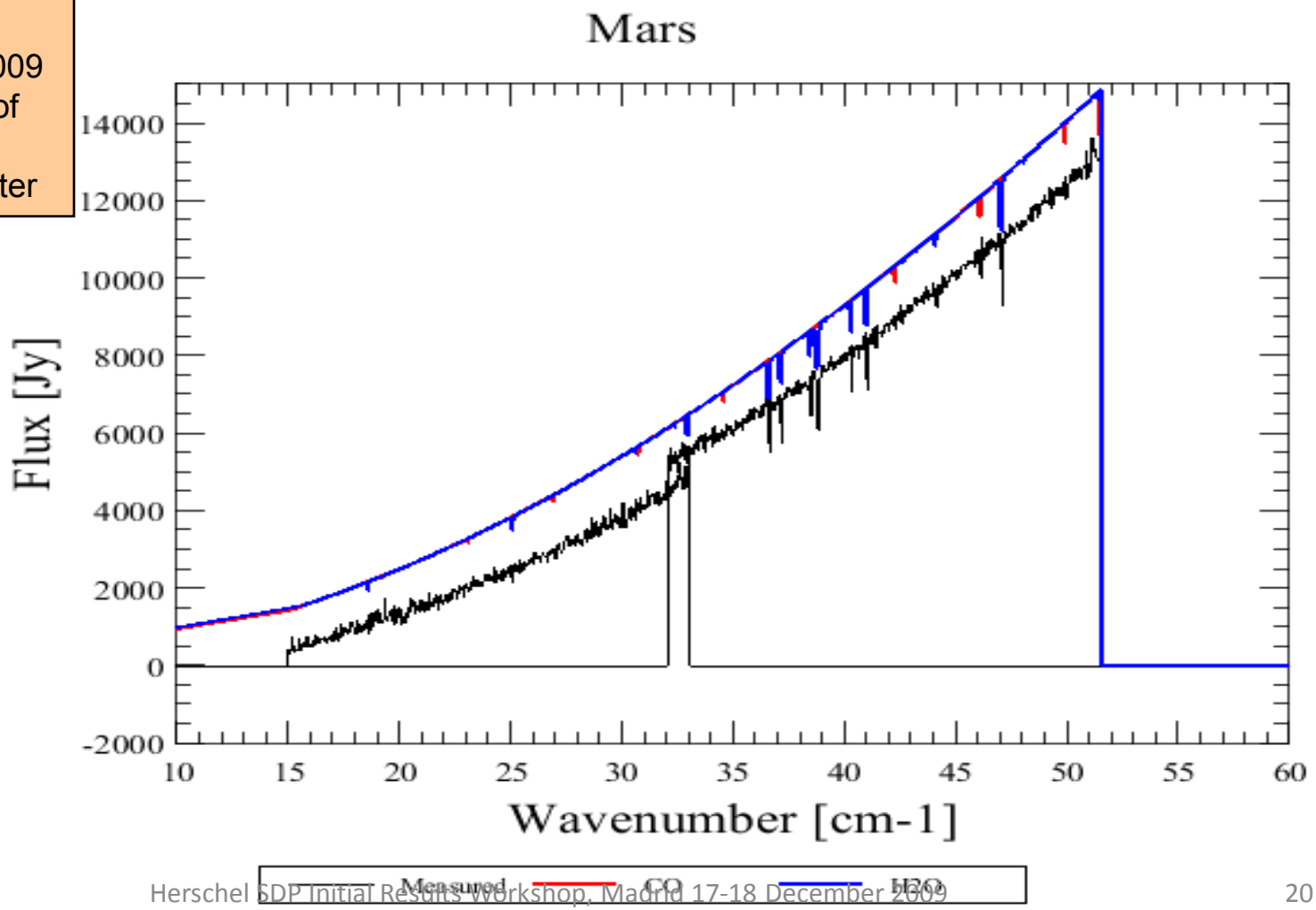
- Multi-layer (60 pressure levels), line by line code
- Line parameters from HITRAN database
- Mars Continuum Emission Model Tool, by Rudy, D.J., et al. 1987, Icarus, 71, 159
- High resolution model spectra convolved to PACS and SPIRE resolution

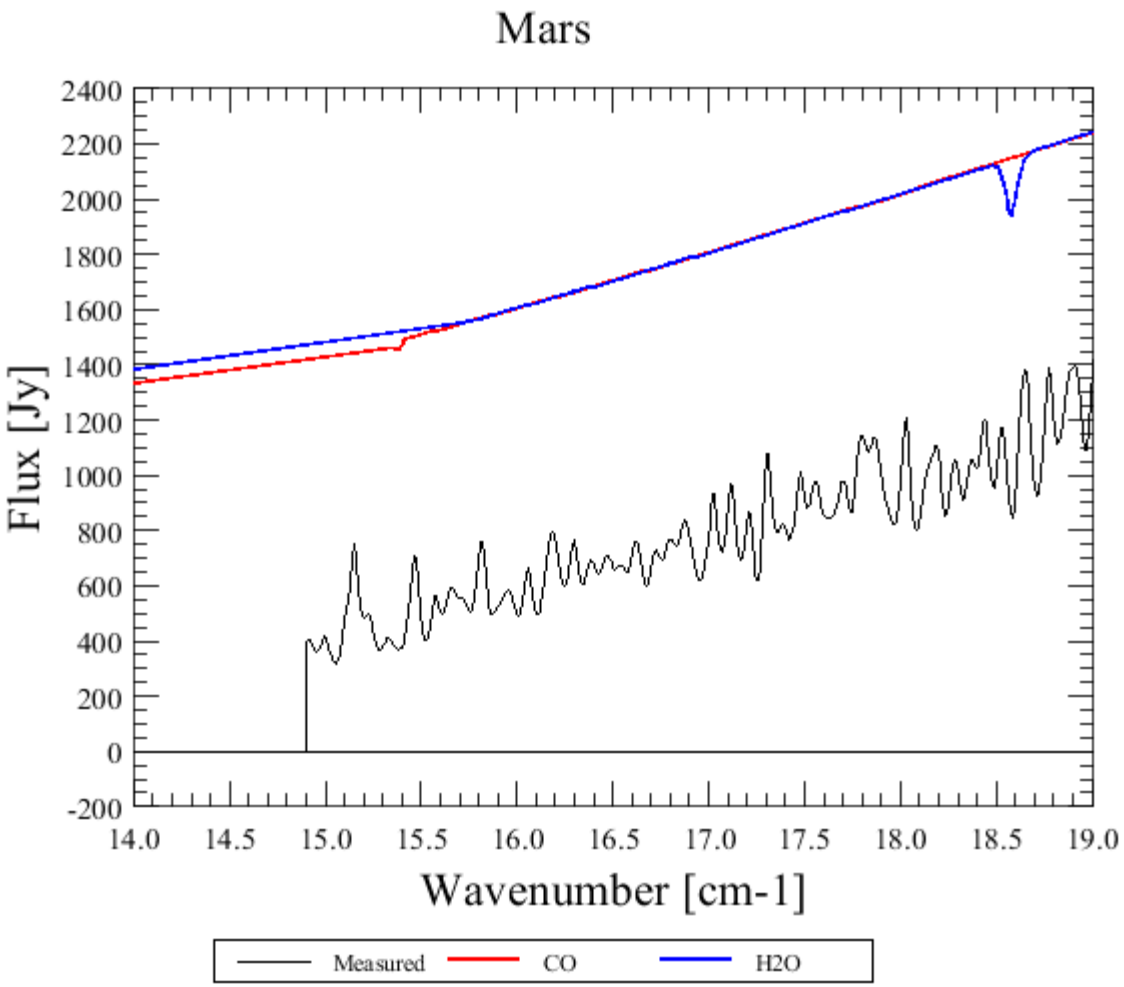
Model profiles



Mars observations with SPIRE

SPIRE Observation of Mars:
OD176, 06-Nov-2009
Angular diameter of Mars: 8.2”
SPIRE Spectrometer




Mars
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
Flux [Jy]
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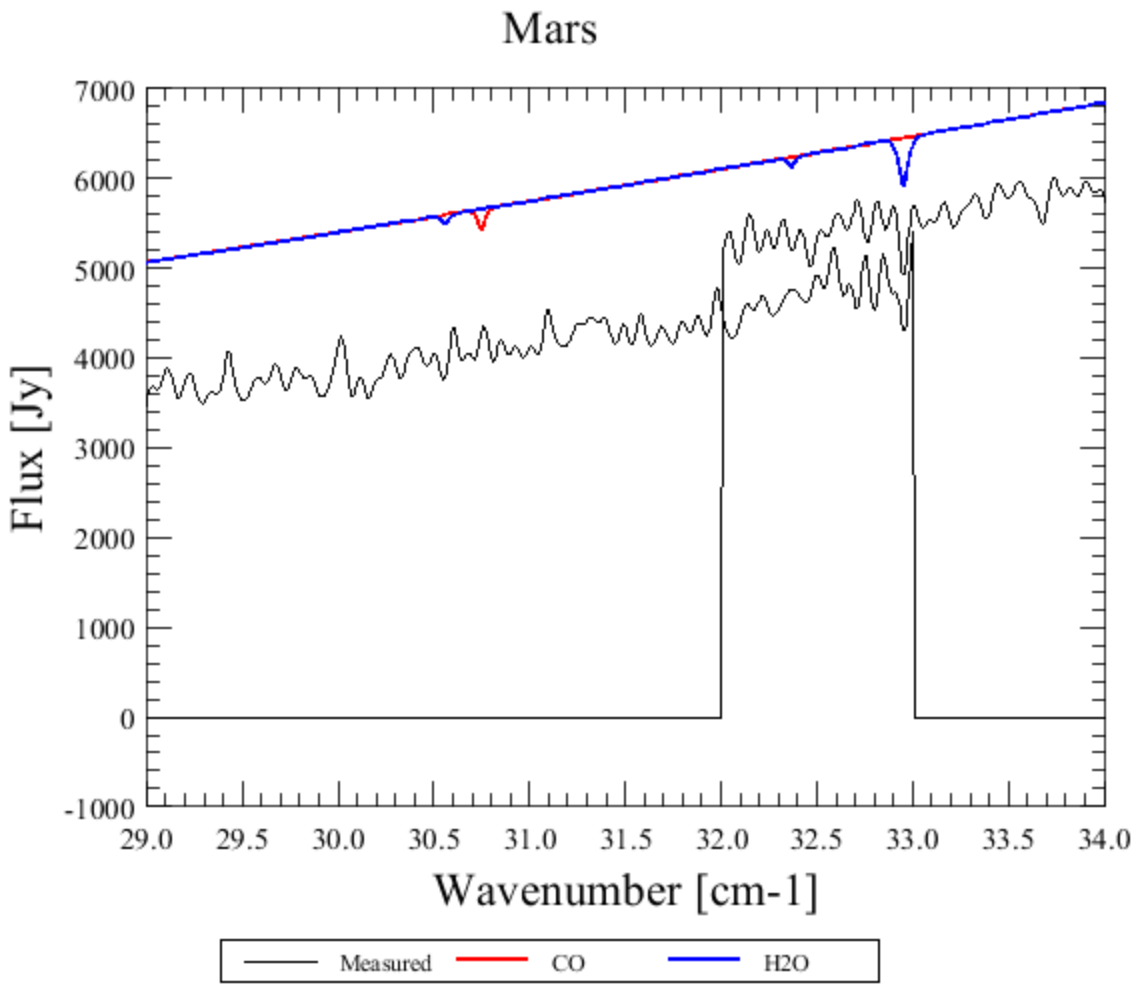
14.5
15.0
15.5
16.0
16.5
17.0
17.5
18.0
18.5
19.0
Wavenumber [cm-1]
Measured
CO
H2O

21


Mars
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6000
5000
4000
3000
2000
1000
0
-1000
Flux [Jy]
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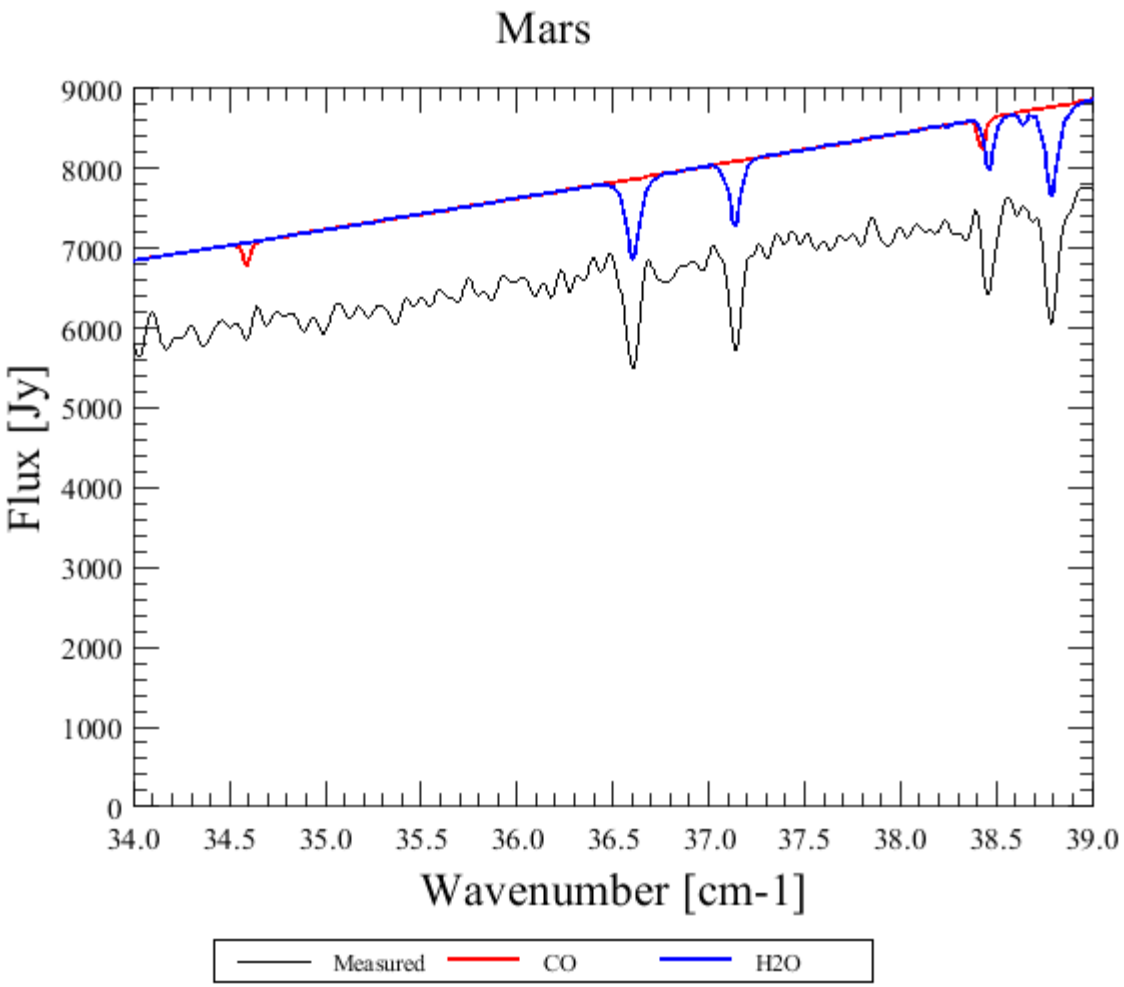
29.5
30.0
30.5
31.0
31.5
32.0
32.5
33.0
33.5
34.0
Wavenumber [cm-1]
Measured
CO
H2O

22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7000
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37.0
37.5
38.0
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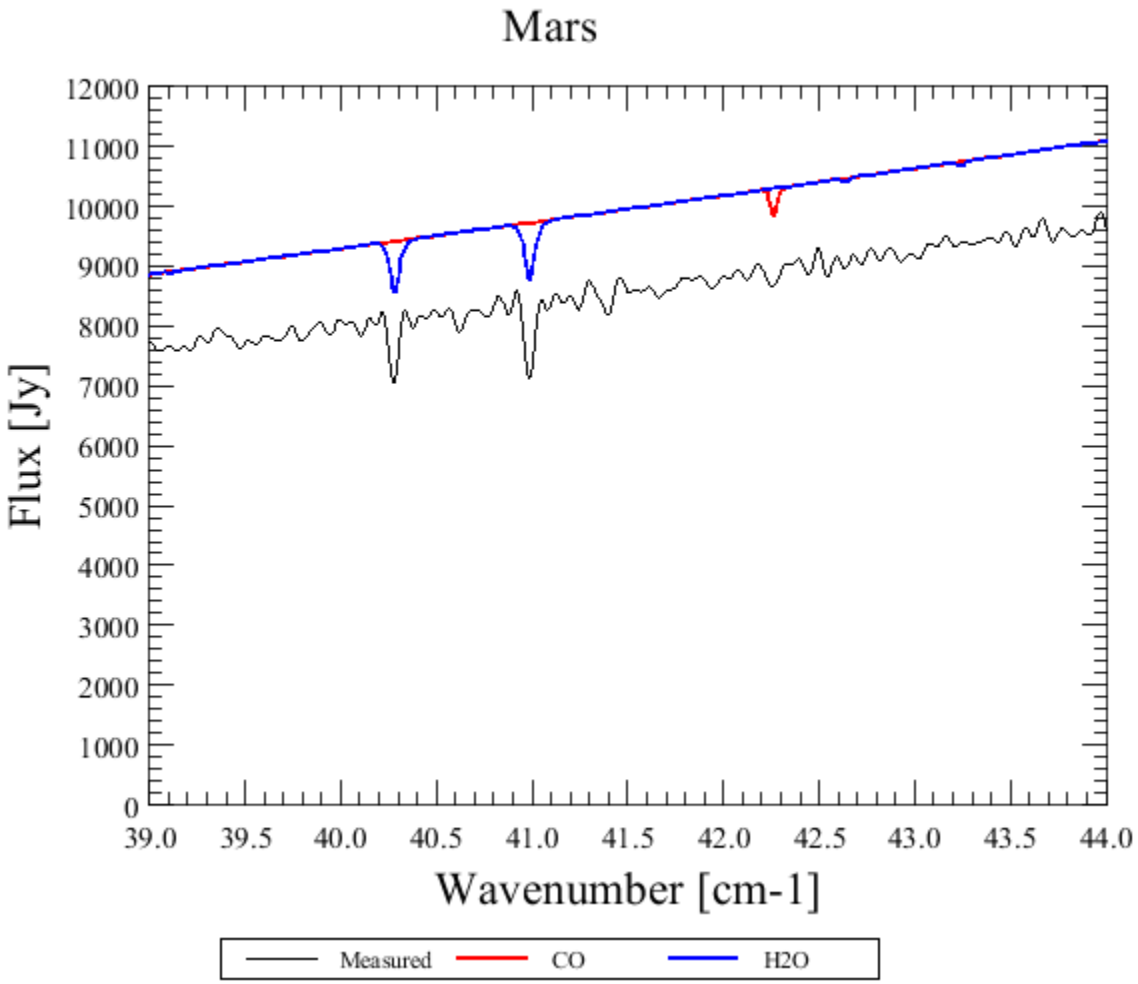
Wavenumber [cm-1]
Measured
CO
H2O

23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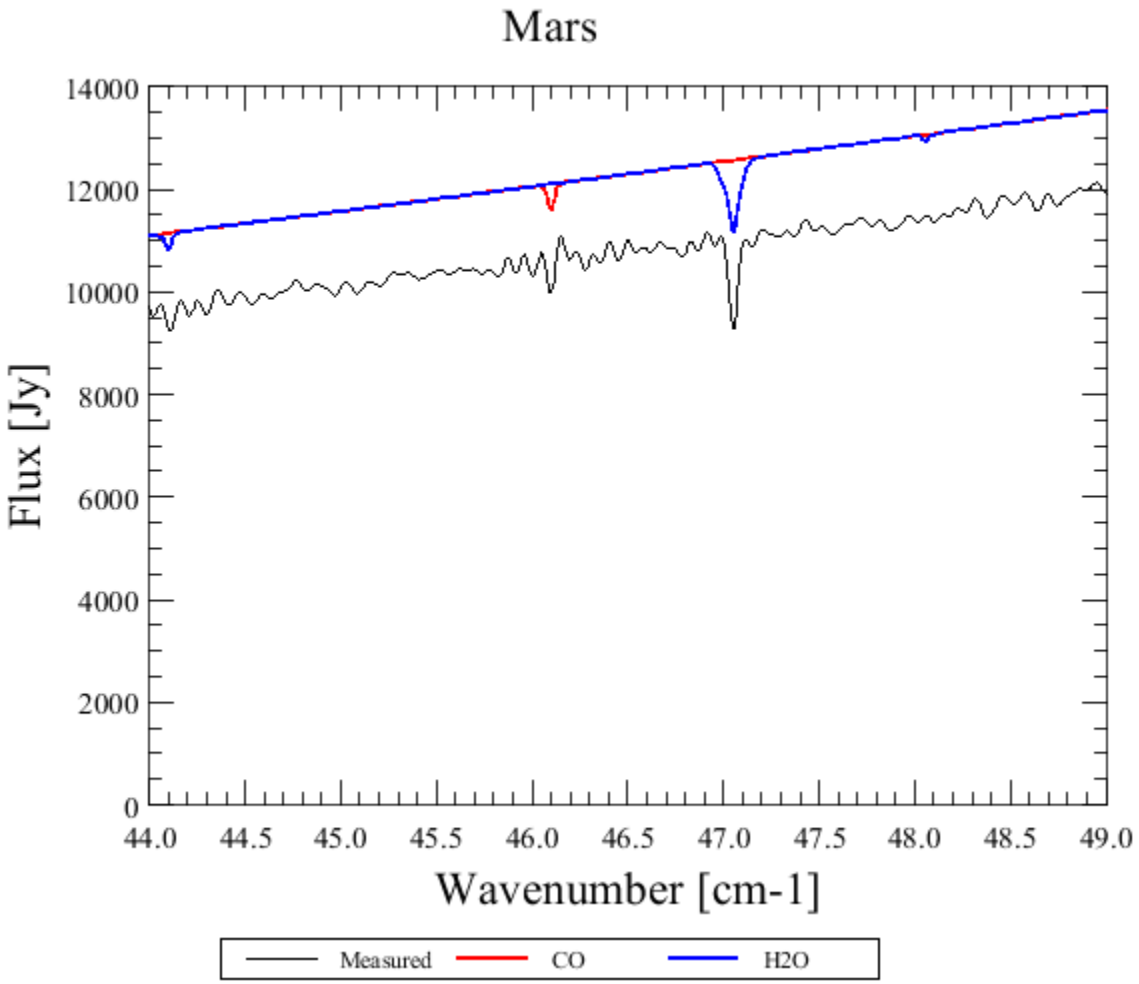
42.0
42.5
43.0
43.5
44.0
Wavenumber [cm-1]
Measured
CO
H2O

24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10000
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6000
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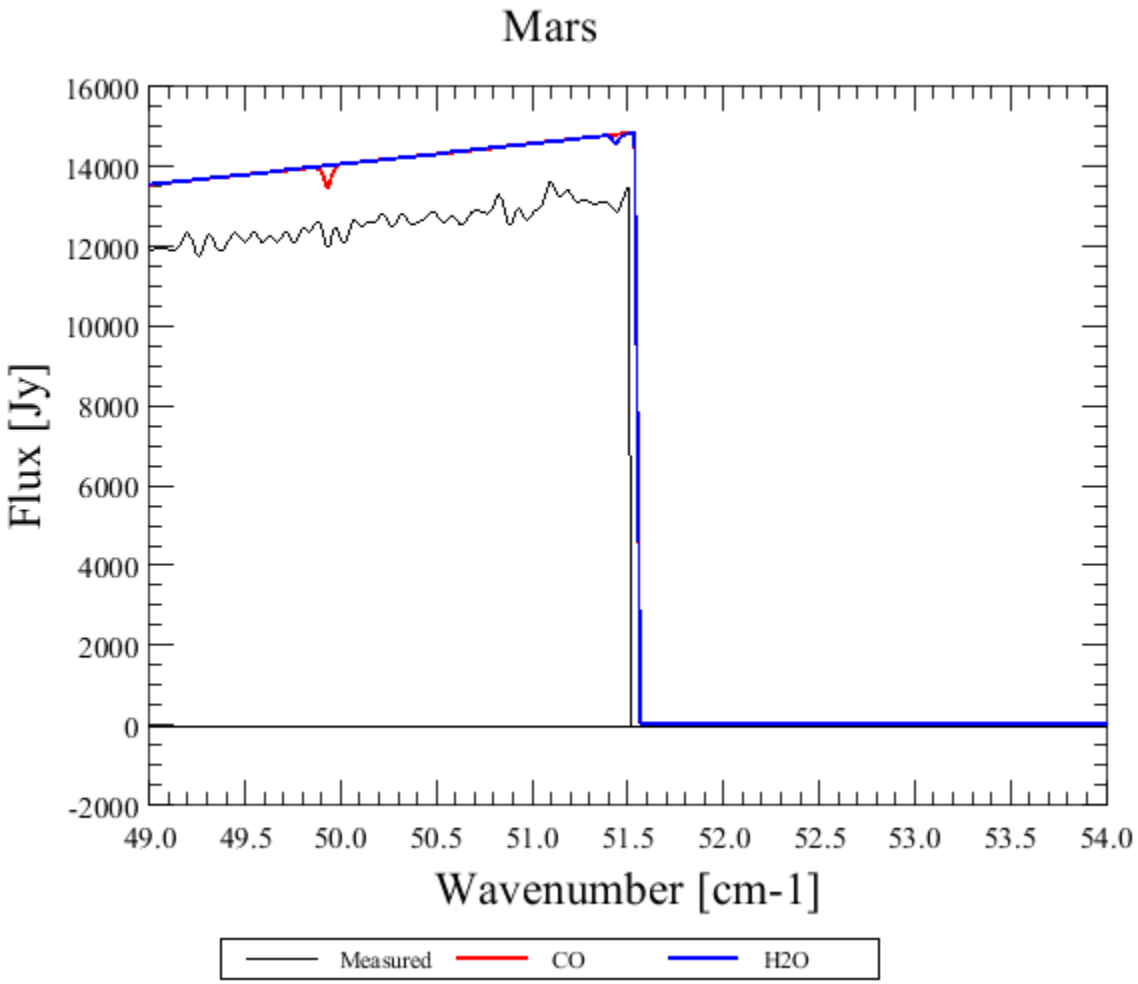
Wavenumber [cm-1]
Measured
CO
H2O

25


Mars
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Flux [Jy]
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51.0
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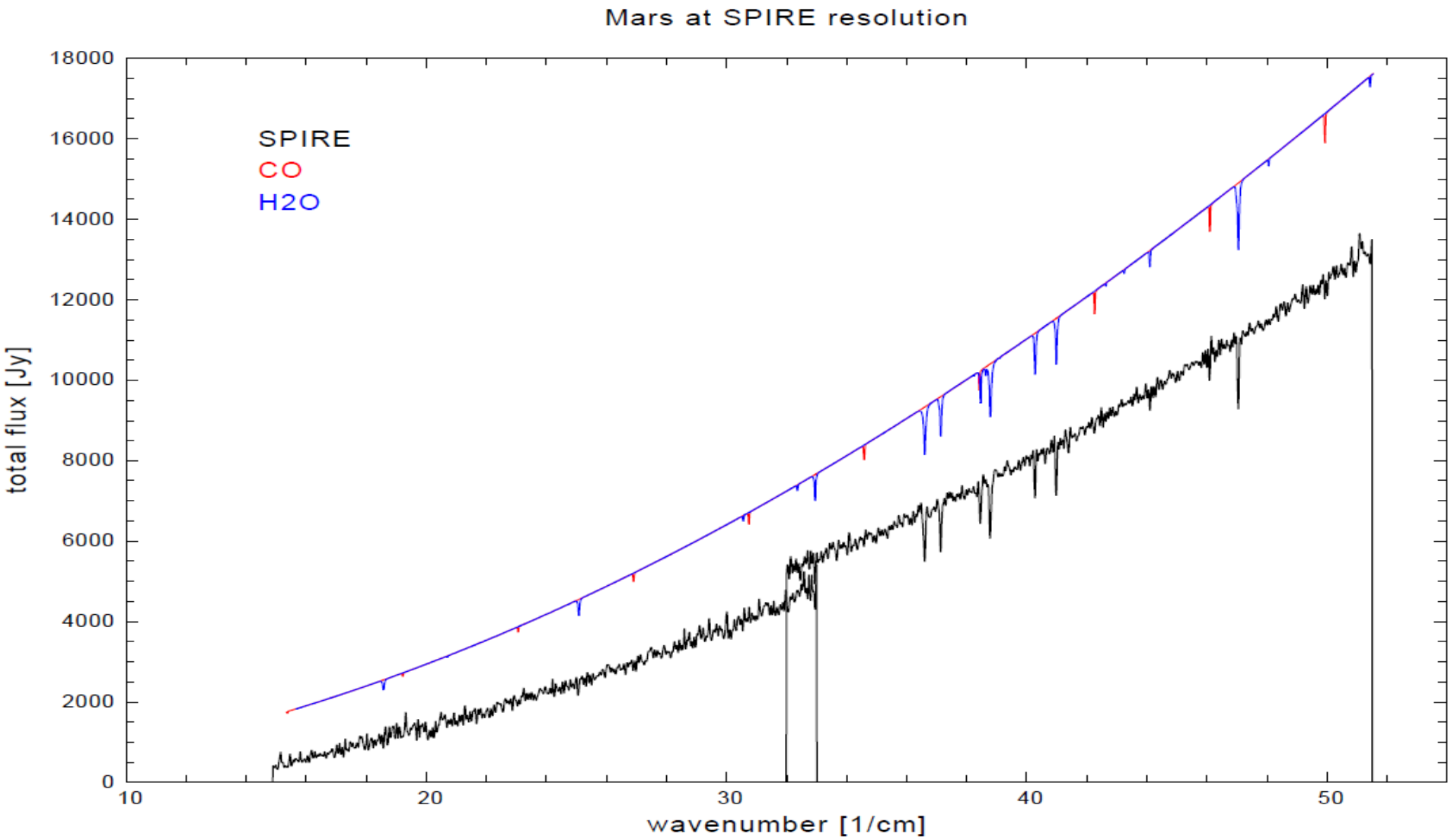
52.5
53.0
53.5
54.0
Wavenumber [cm-1]
Measured
CO
H2O

26

Model update



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.