The origin of external oxygen in Jupiter and Saturn's environments

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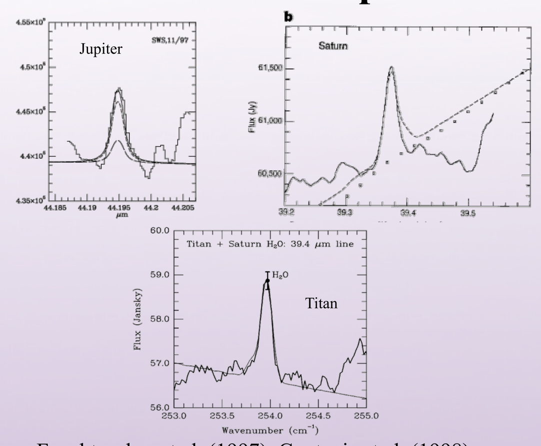
Introduction

Detection of H_2O with ISO in the stratospheres of the giant planets and Titan



H_2O seen in emission

H_2O is in the stratosphere above the tropospheric cold trap

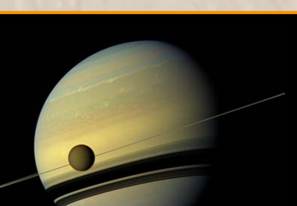
external source of H_2O
icy rings/satellites, comets, interplanetary dust

Feuchtgruber et al. (1997), Coutenis et al. (1998), Lellouch et al (2002)

The « pre-Herschel » picture at Jupiter and Saturn

Jupiter: H_2O: comet SL9?
CO: comet SL9 + interior
CO_2: comet SL9

Bézard et al. (2002), Lellouch et al. (2002), Cavalié et al. (2008,2012)



Saturn: H_2O: ?
CO: comet (+ interior?)
CO_2:?
Titan: H_2O, CO, CO_2: ?

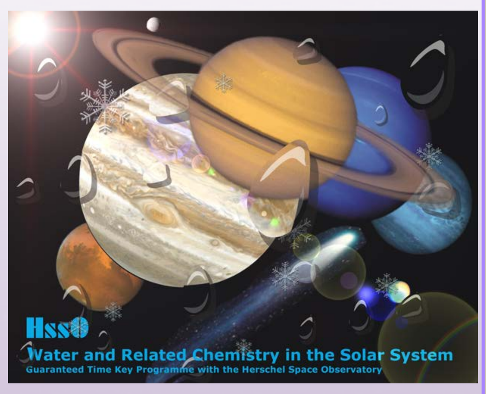
Cavalié et al. (2009,2010)

The HssO Key Program

Disentangling the various sources of H_2O at Jupiter and Saturn

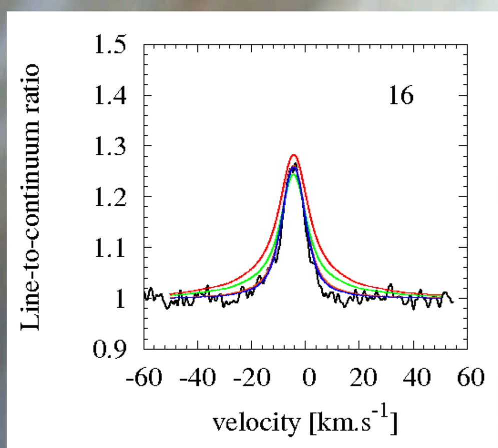
Key objective of the HssO project
« Water and related chemistry in the Solar System », a Herschel Guaranteed Time Key Program

(Hartogh et al. 2009)

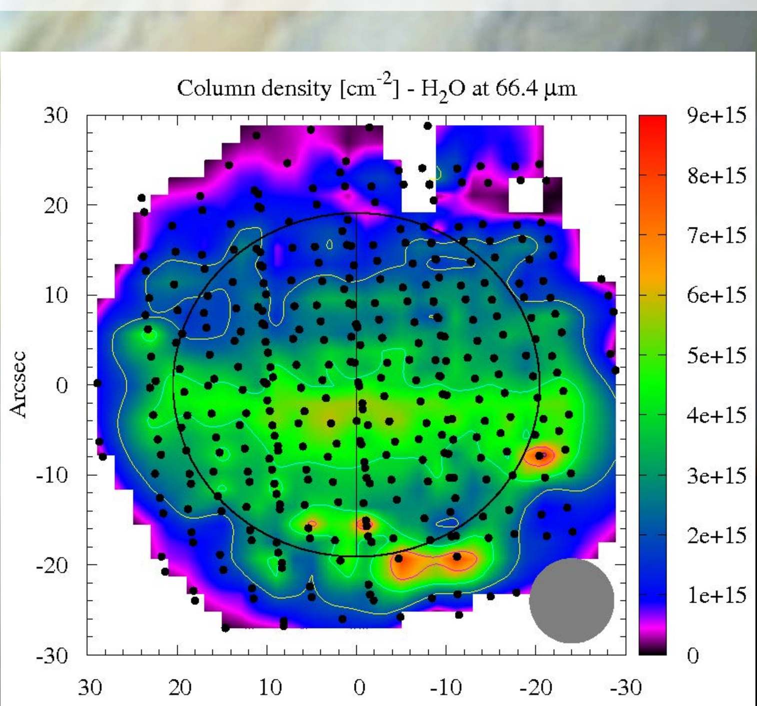


The source of H_2O in Jupiter's stratosphere: comet Shoemaker-Levy 9

In July 1994, the Shoemaker-Levy 9 (SL9) comet « String of Pearls » hit Jupiter at 44°S. These impacts deposited material in the atmosphere of the planet (Lellouch et al. 1995). The detection of H_2O with ISO by Feuchtgruber et al. (1997) in the Jovian stratosphere raised the question whether this H_2O originated from SL9.



HIFI observation (H_2O at 1670GHz)
➡ H_2O is in the middle stratosphere



PACS observation (H_2O at 66.4µm)
➡ 2-3x more H_2O in the southern hemisphere

H_2O comes from SL9

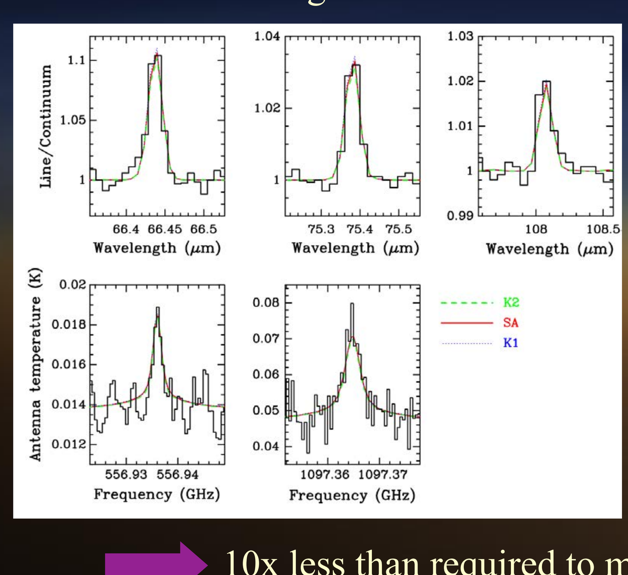
ISO, SWAS and Odin observations have only brought tentative clues regarding a cometary origin of H_2O in Jupiter's stratosphere (Lellouch et al. 2002; Cavalié et al. 2008, 2012).

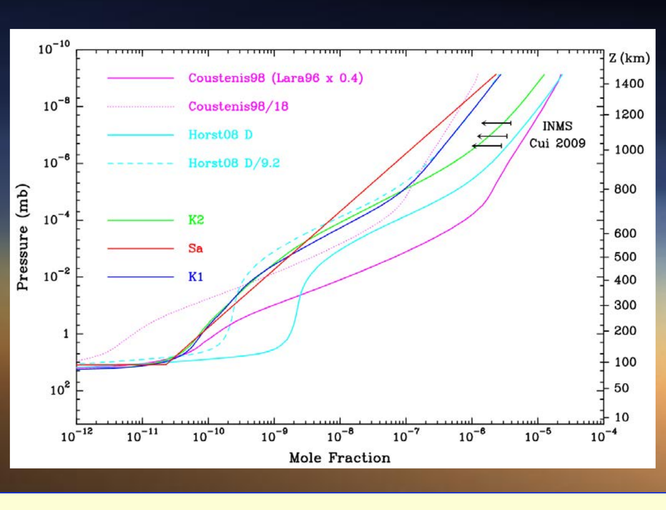
With Herschel and its unprecedented spectral resolution (HIFI) and spatial resolution (PACS) at H_2O rotational frequencies, **Cavalié et al. (2013)** have demonstrated that the spatial distribution of water in Jupiter's stratosphere is clear evidence that a recent comet, i.e., the Shoemaker-Levy 9 comet, is the principal source of water in Jupiter**.**

What is observed today is a remnant of the oxygen delivery by the SL9 comet at 44°S in July 1994.

H_2O at Titan: interplanetary dust particles or Enceladus geysers?

Moreno et al. (2012) have used a combination observations of three unresolved H_2O rotational lines at 66.4, 75.4 and 108.0 µm with PACS, and two spectrally-resolved transitions at 557 GHz (538 µm) and 1097 GHz (273 µm) with HIFI, to infer the vertical profile of H_2O over the 100-450 km altitude range.





OH/H_2O influx = (2.7–3.4) 10^5 mol.cm^{-2}.s^{-1}

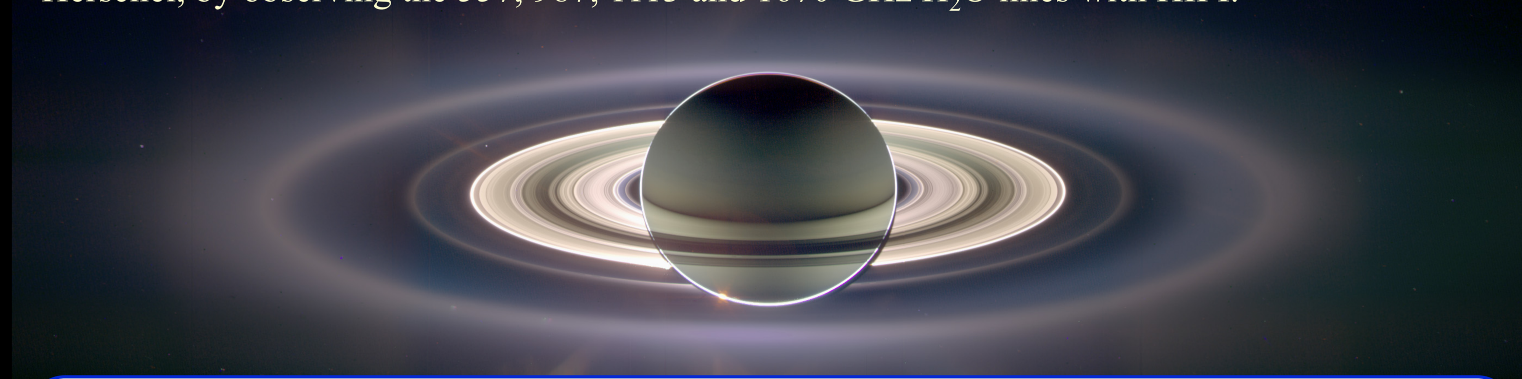
➡ 10x less than required to match the observed CO_2 mole fraction
H_2O has a shorter atmospheric lifetime than CO_2 (9 years vs 450 years)

➡ Oxygen influx into Titan currently much smaller than averaged over the past centuries?

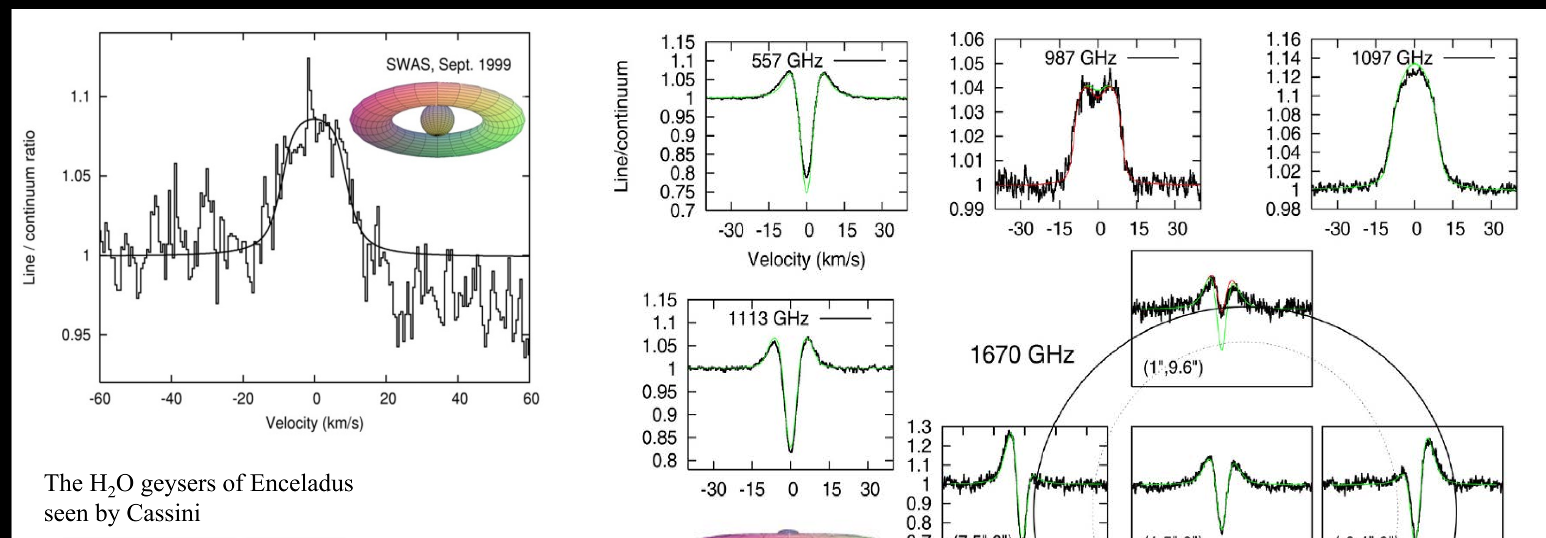
Both interplanetary dust particles and Enceladus' activity appear to provide sufficient supply for the current Titan H_2O. Enceladus is tentatively favored as potentially more prone to time variability (Moreno et al 2012).

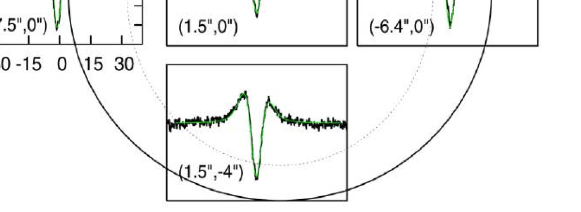
Detection of the Enceladus torus at Saturn

Cryovolcanic activity at the south pole of Enceladus produces spectacular geysers, mainly composed of H_2O vapor and ice particles. The emitted molecules form a torus around Saturn, at Enceladus orbital distance. **Hartogh et al. (2011)** have detected this H_2O vapor torus with Herschel, by observing the 557, 987, 1113 and 1670 GHz H_2O lines with HIFI.

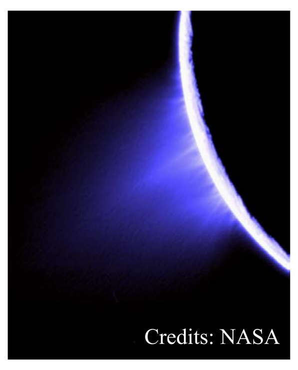


The measured H_2O column density of ~4x10^{13} cm^{-2} in the equatorial plane, along with estimations made on the H_2O flux from the torus to Saturn's atmosphere, indicate that **Enceladus is thus the likely source of Saturn's external H_2O (Hartogh et al. 2011)**. An additional confirmation could be provided by the latitudinal distribution of H_2O on Saturn.





The H_2O geysers of Enceladus seen by Cassini



Change in the observation geometry from 1999 to 2009 (see ring plane inclination)
➡ the H_2O torus of Enceladus, located between Saturn and Herschel, is observed in absorption on Saturn's emission spectrum!

Conclusion

The current picture at Jupiter and Saturn + Titan

Jupiter: H_2O: comet SL9
CO: comet SL9 + interior
CO_2: comet SL9

Bézard et al. (2002), Lellouch et al. (2002), **Cavalié et al. (2013)**

Saturn: H_2O: Enceladus
CO: comet (+ interior?)
CO_2: Enceladus?
Titan: H_2O,CO, CO_2: Enceladus?

Cavalié et al. (2009,2010), **Hartogh et al. (2011), Moreno et al. (2012)**

Perspectives

ALMA — SWI Submillimeter Wave Instrument — Solstice Mission

+ Cosmic Vision L2-L3 proposed mission concepts (Mousis et al. 2013 ; Tobie et al. 2013)

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