

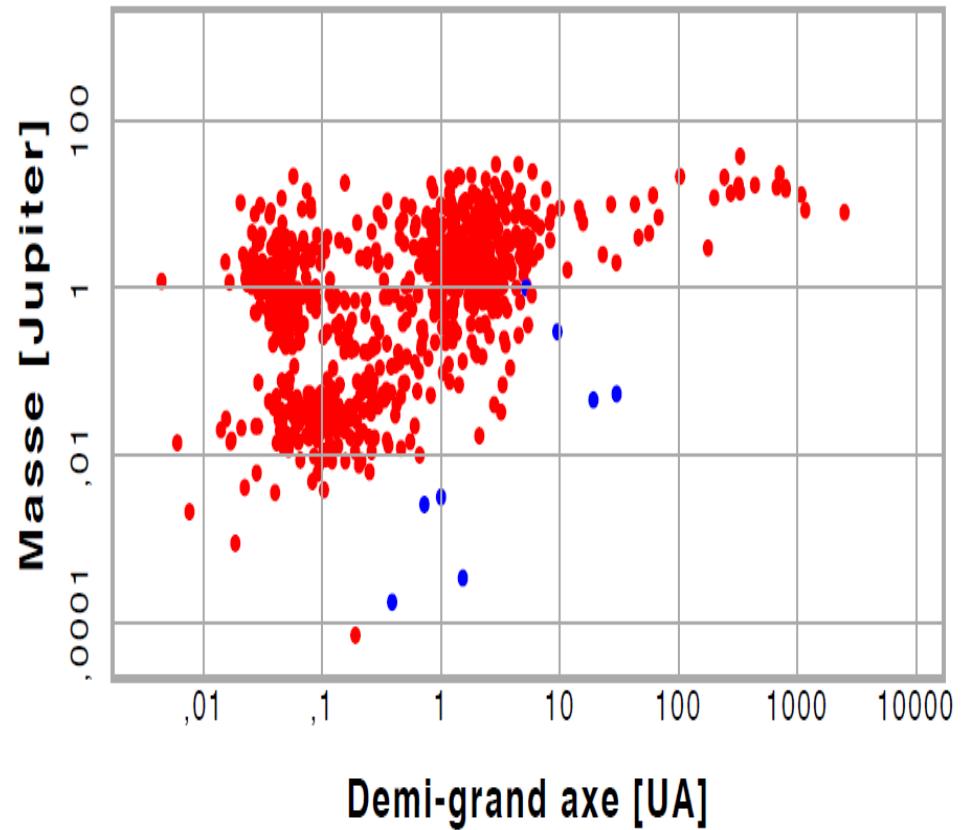
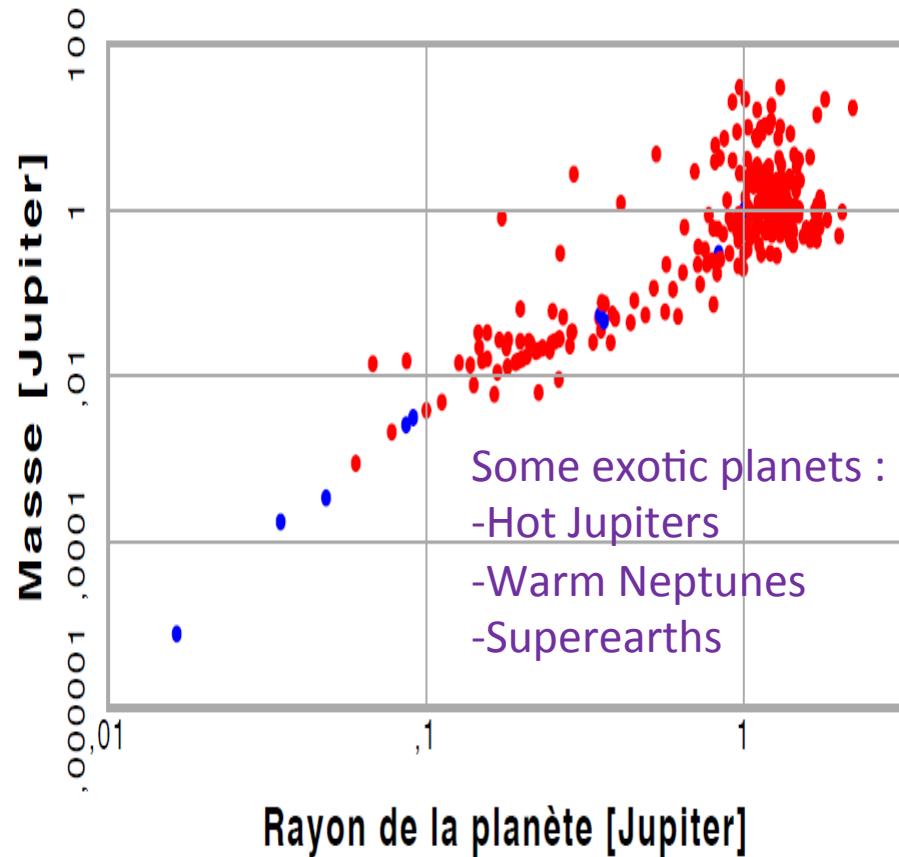
From planets to exoplanets: the case for spectroscopy with EChO

Pierre Drossart

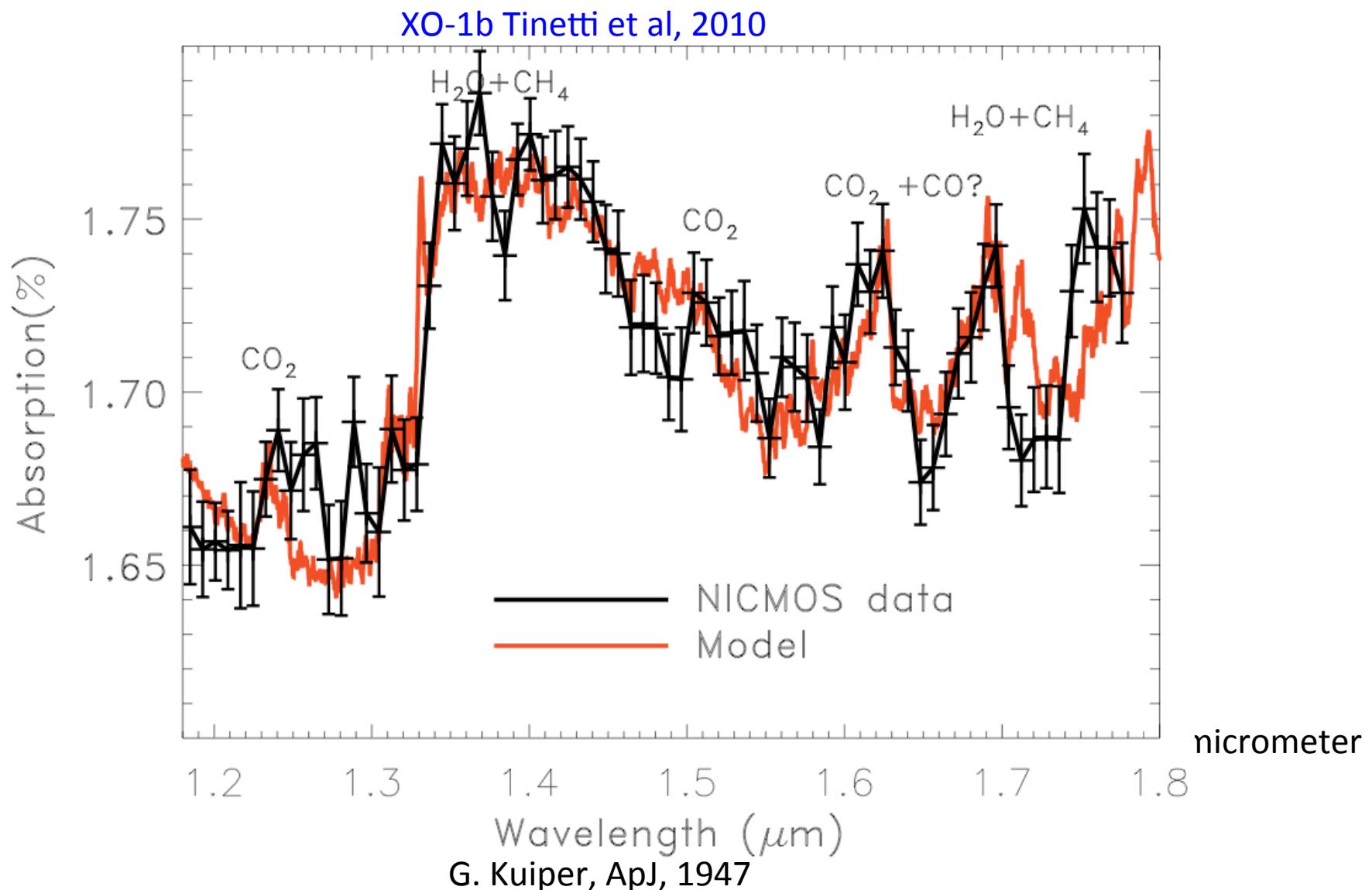
LESIA, Observatoire de Paris, France

Solar system planets and exoplanets

Are the Solar System planets good templates for exoplanets ? No!



...but processes learned from planets apply to exoplanets too !



Early times in planetary IR spectroscopy ...

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND
ASTRONOMICAL PHYSICS

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NUMBER 2

SPECTROSCOPIC EVIDENCE FOR VEGETATION ON MARS

WILLIAM M. SINTON
Smithsonian Astrophysical Observatory
Received May 6, 1957

ABSTRACT

A new test for the presence of vegetation on Mars depends on the fact that all organic molecules have absorption bands in the vicinity of 3.4μ . These bands have been studied in the reflection spectrum of terrestrial plants, and it is found that for most plants a doublet band appears which has a separation of about 0.1μ and is centered about 3.46μ . Spectra of Mars taken during the 1956 opposition indicate the probable presence of this band. This evidence and the well-known seasonal changes of the dark areas make it extremely probable that vegetation in some form is present.

Molecular spectroscopy for planetary atmospheres

See Tennyson and Medvedev talks at the conference

Giant planets

atmosphere : H₂, He, + minor const.
main IR absorbers : CH₄, NH₃
minor absorbers : PH₃, CO, H₂O, etc.

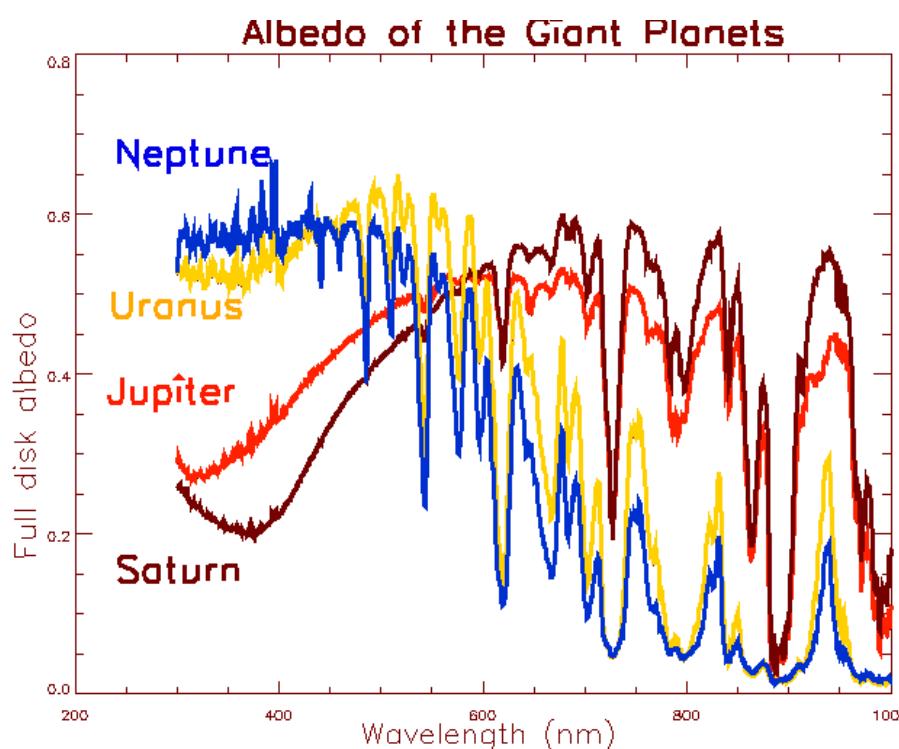
Telluric Planets

atmosphere : CO₂, N₂
main IR absorber : CO₂
minor absorbers : H₂O, CO, etc.

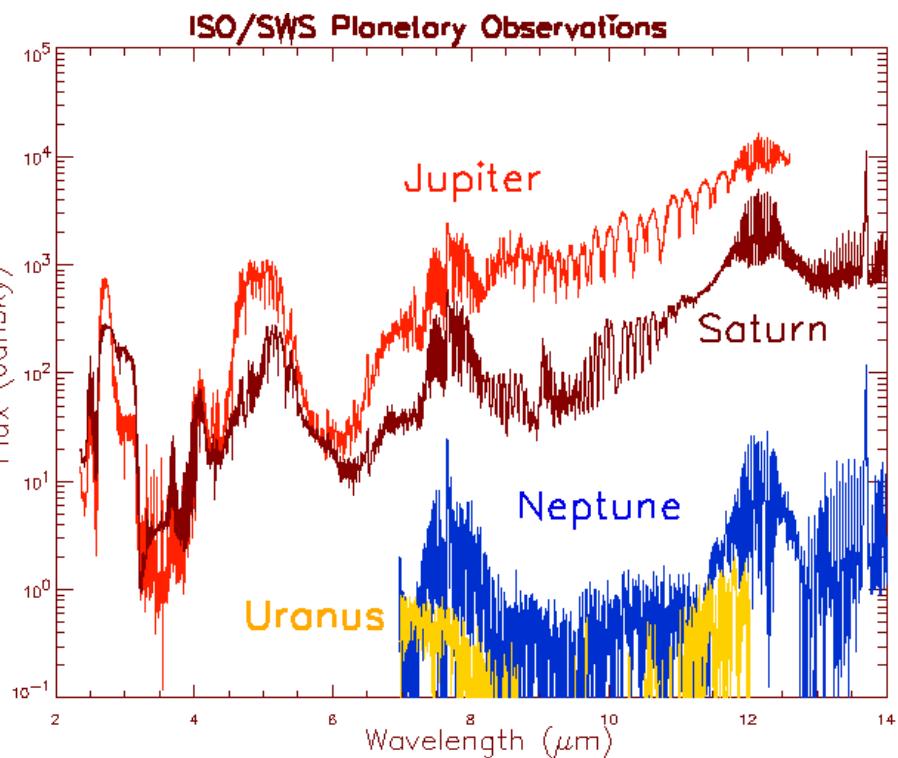
Titan

atmosphere : N₂, CH₄, Ar, ...
main IR absorber : CH₄

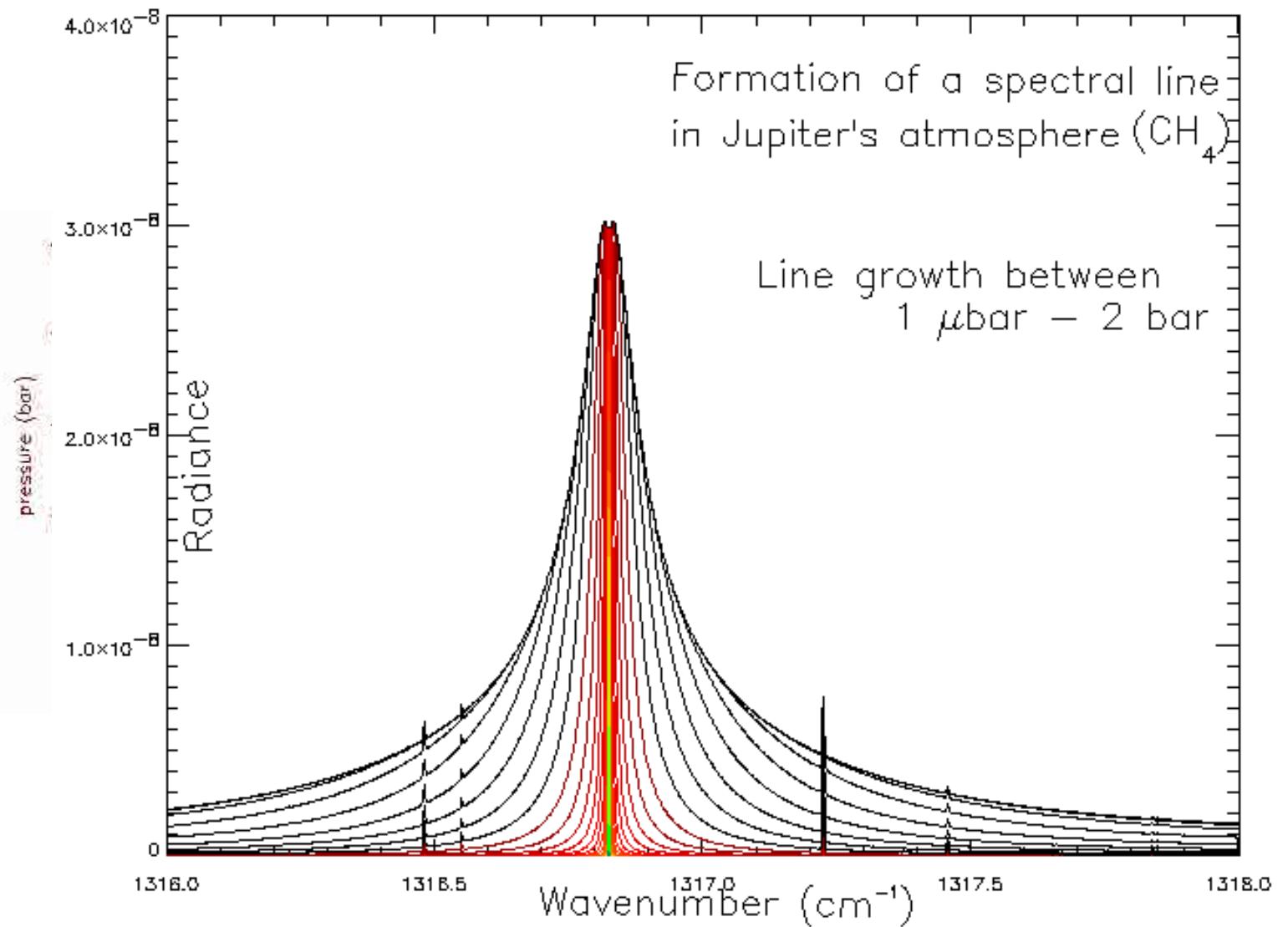
Spectra of Giant Planets



Day side (Reflected sunlight)

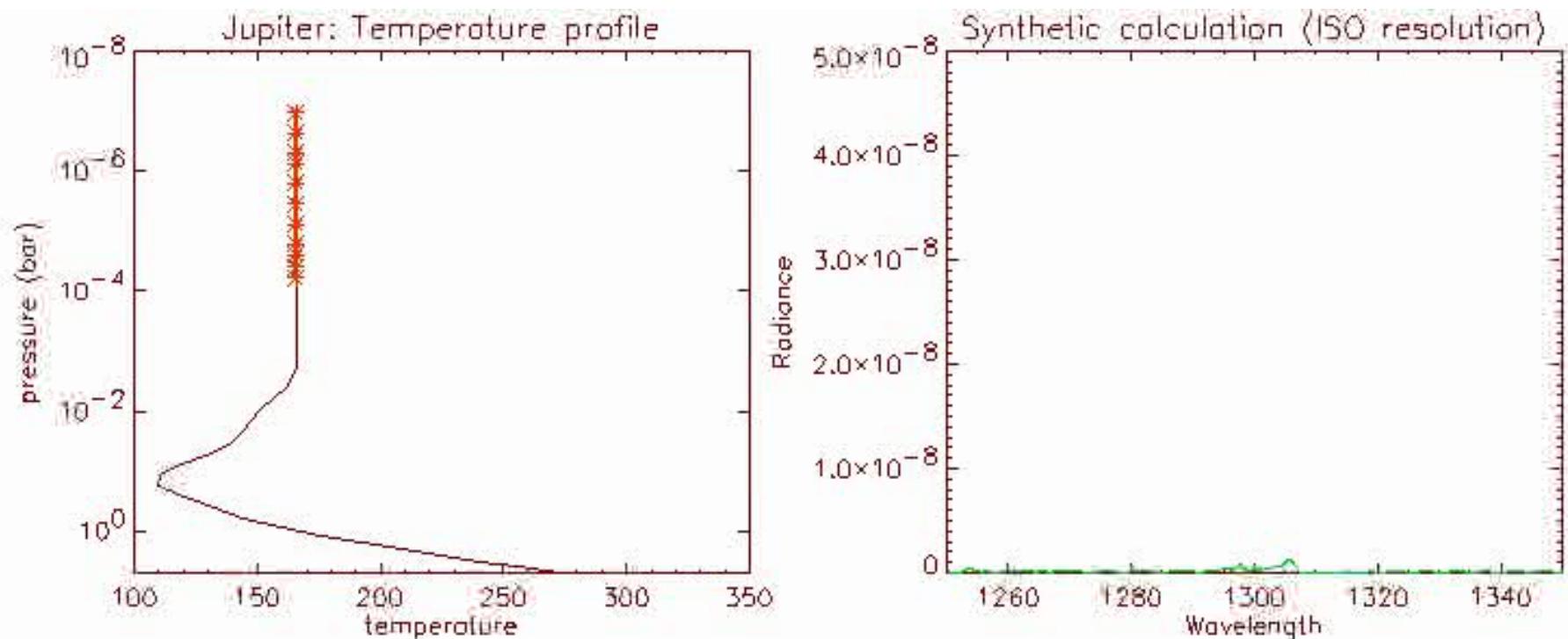


Thermal emission

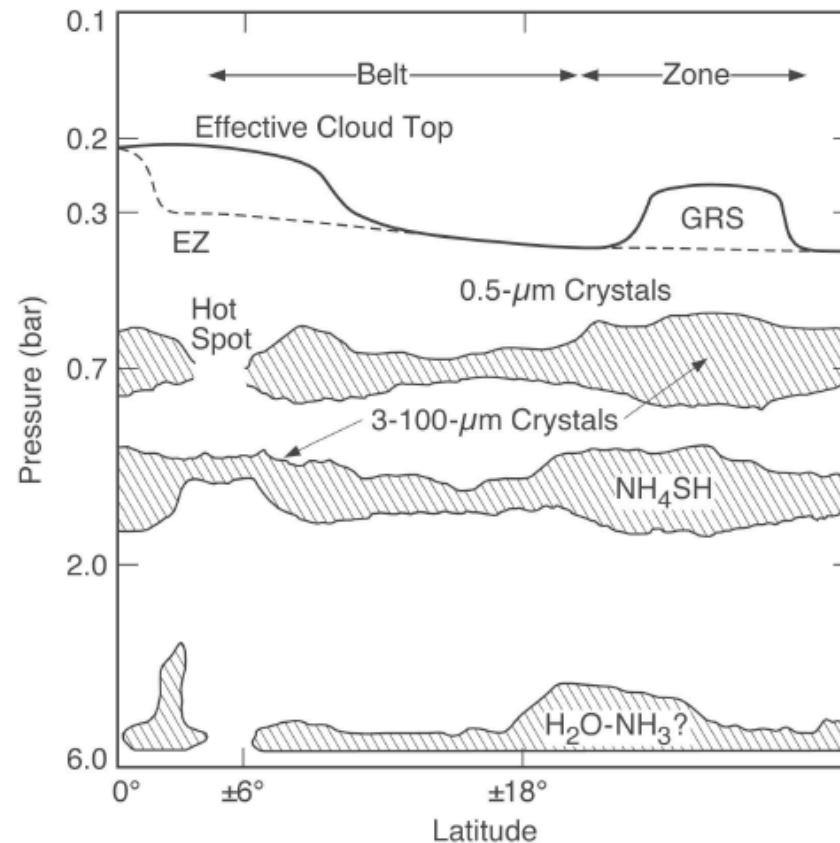


Line formation in Jupiter's atmosphere ($\text{CH}_4 \nu_4$ band)
Growth of line through vertical atmospheric integration

Line formation on Jupiter at 7.8 micron



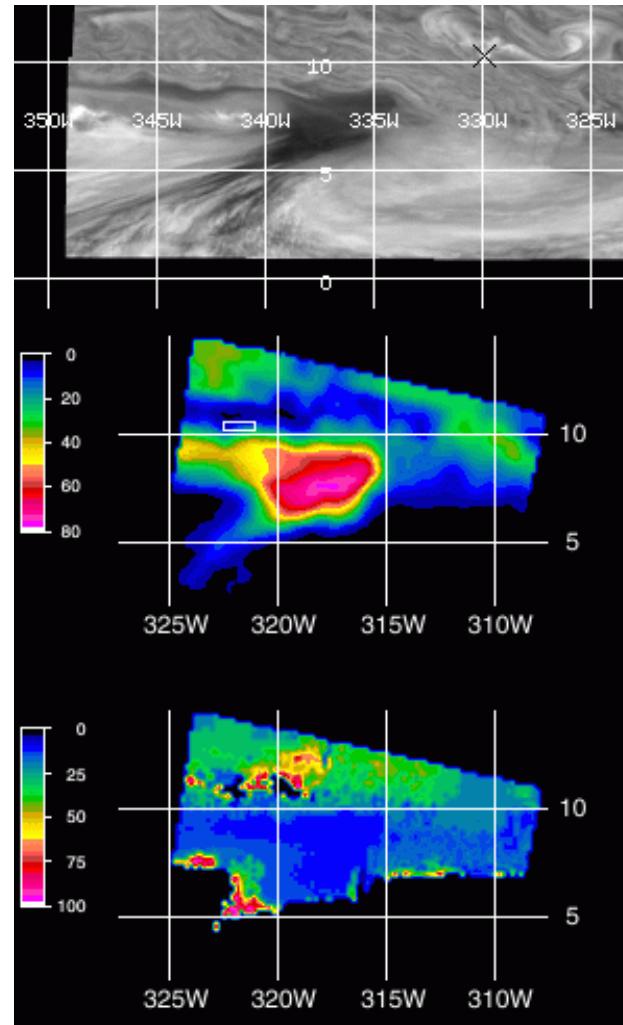
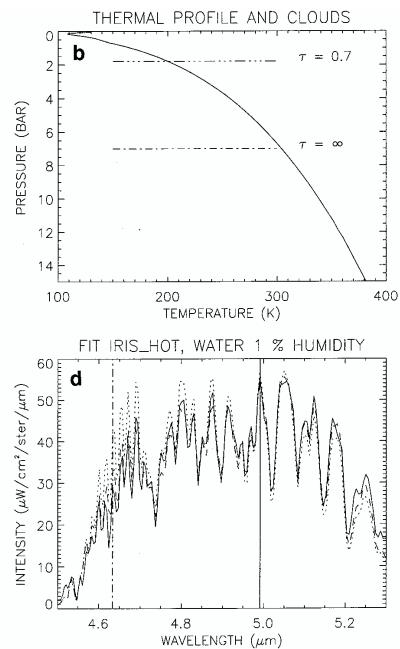
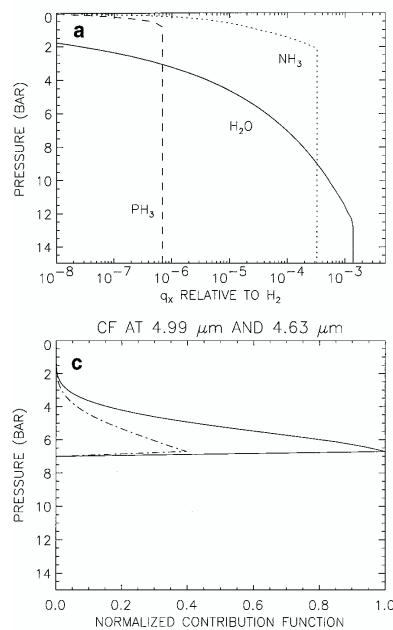
Clouds aerosols, hazes on Jupiter



Jupiter sketch
Structure (West et
al, 2004)

Water at 5 μm as seen by NIMS-Galileo

Roos-Serote et al, 1999



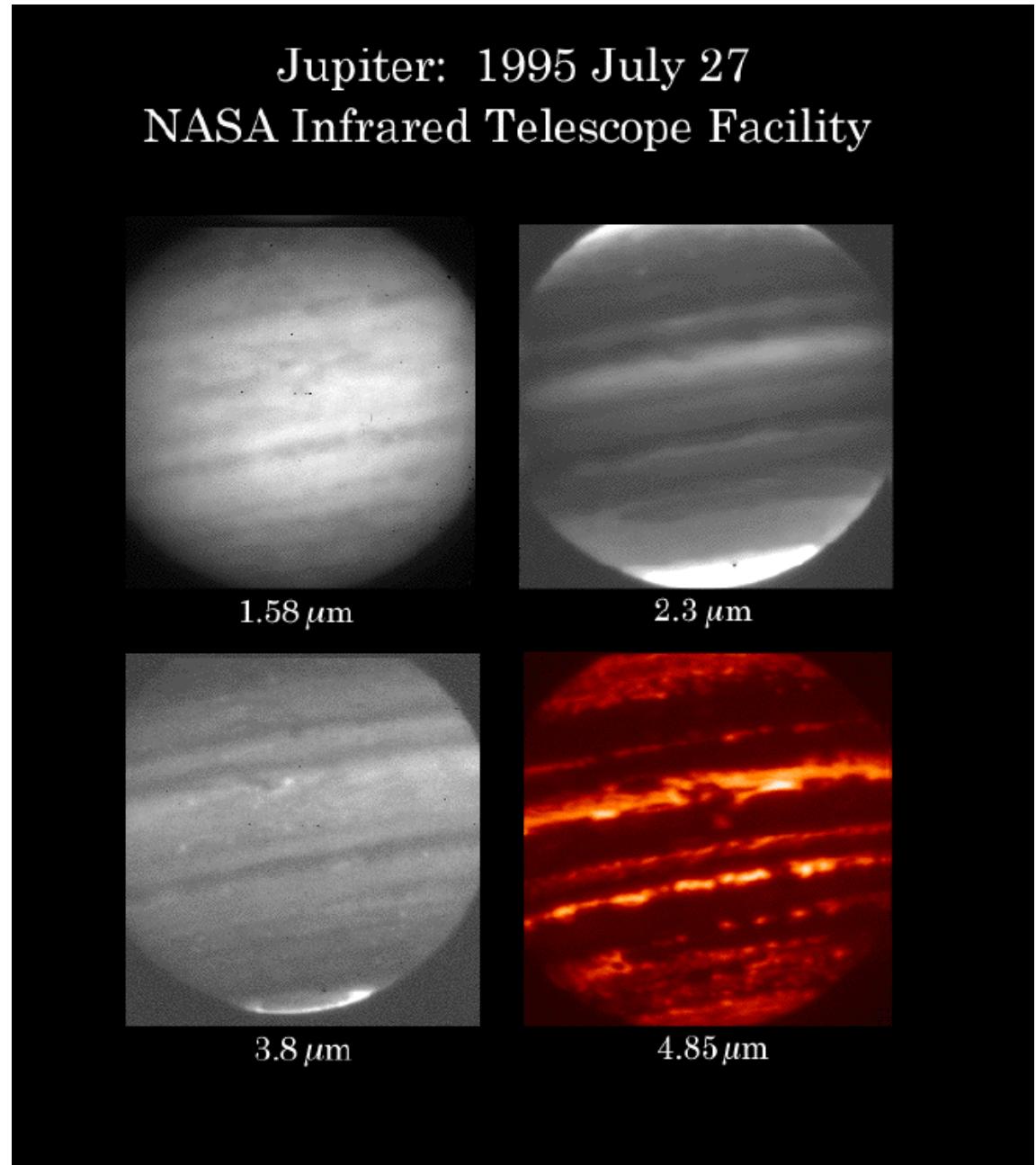
Map of an IR hot spot
on Jupiter (Galileo
Visible camera)

5- μm thermal emission
(Galileo/NIMS)

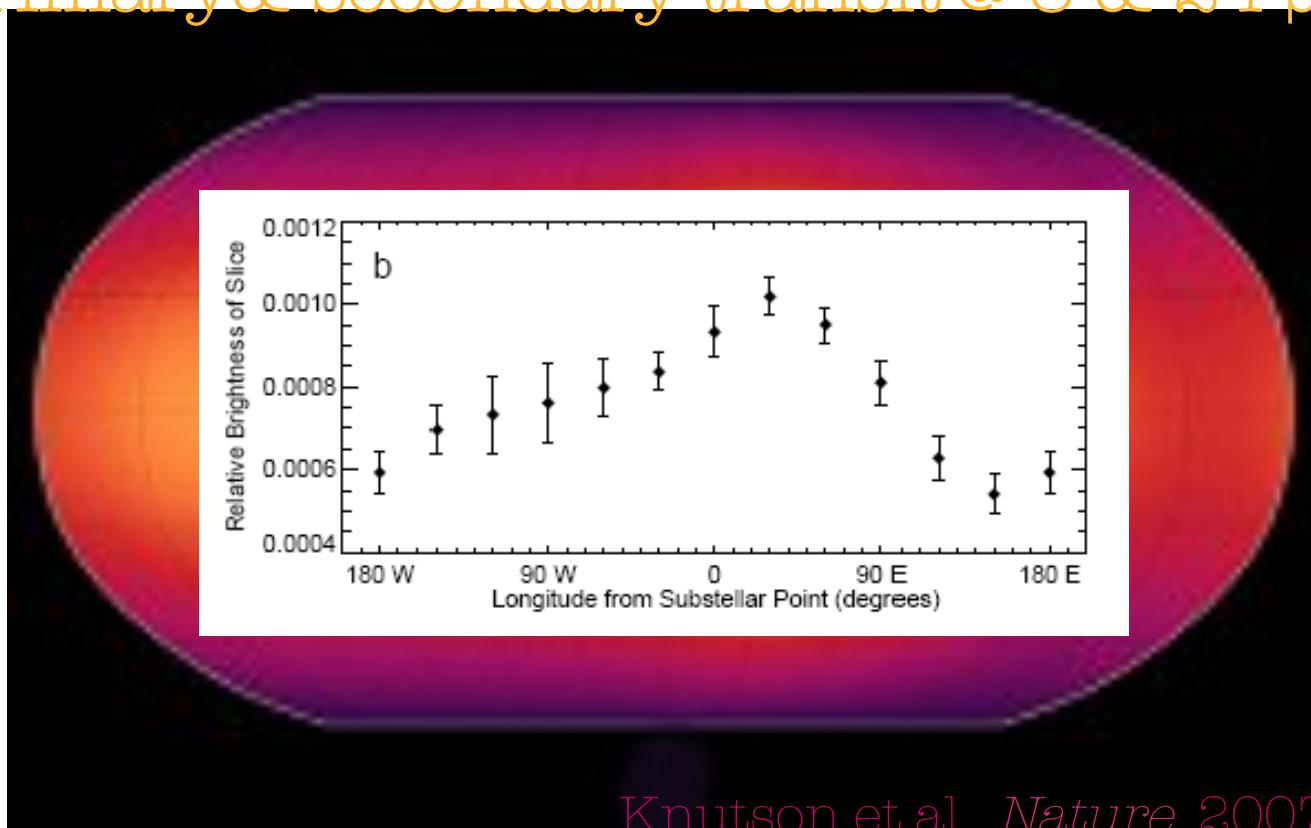
Variations of water vapor
within the hot spot

Morphology of Jupiter

High spatial variability => inhomogeneties with non – linear spectral combination



HD 189733b primary & secondary transit @ 8 & 24 μ m

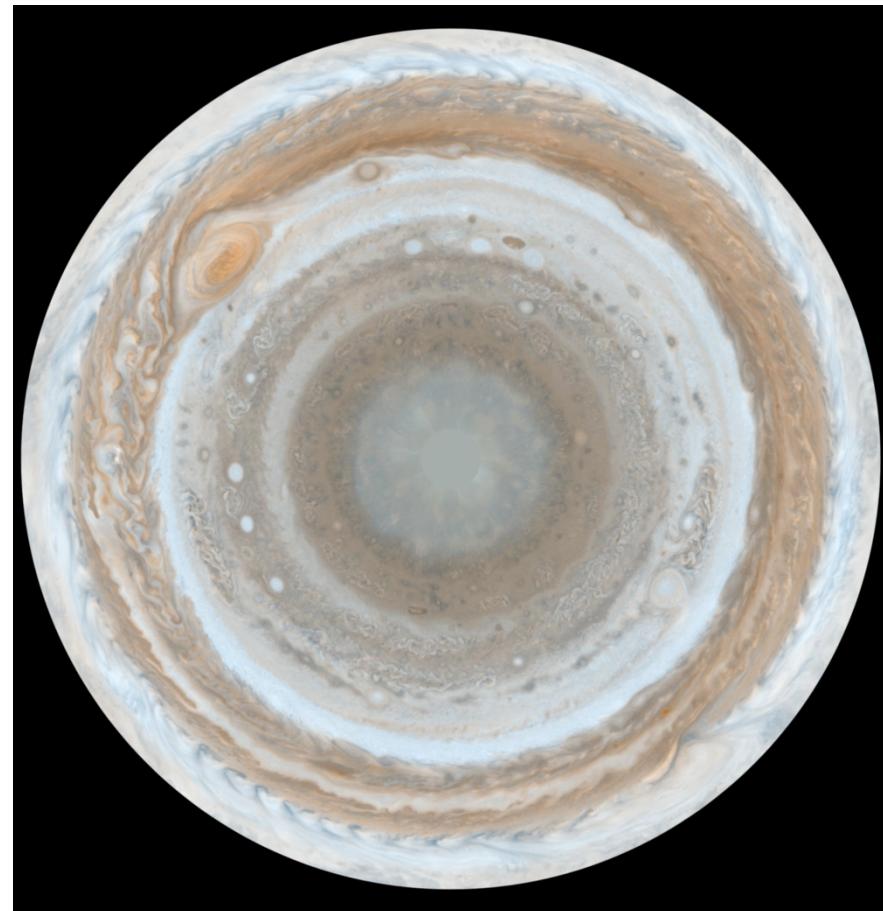


Knutson et al., *Nature*, 2007; ApJ, 2008
EChO Conference
ESTEC - 1-3 July 2013

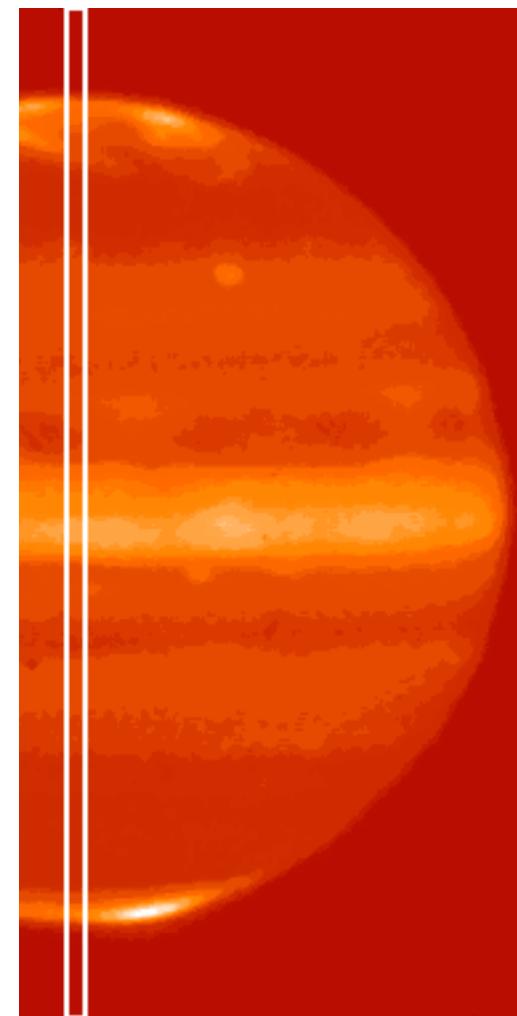
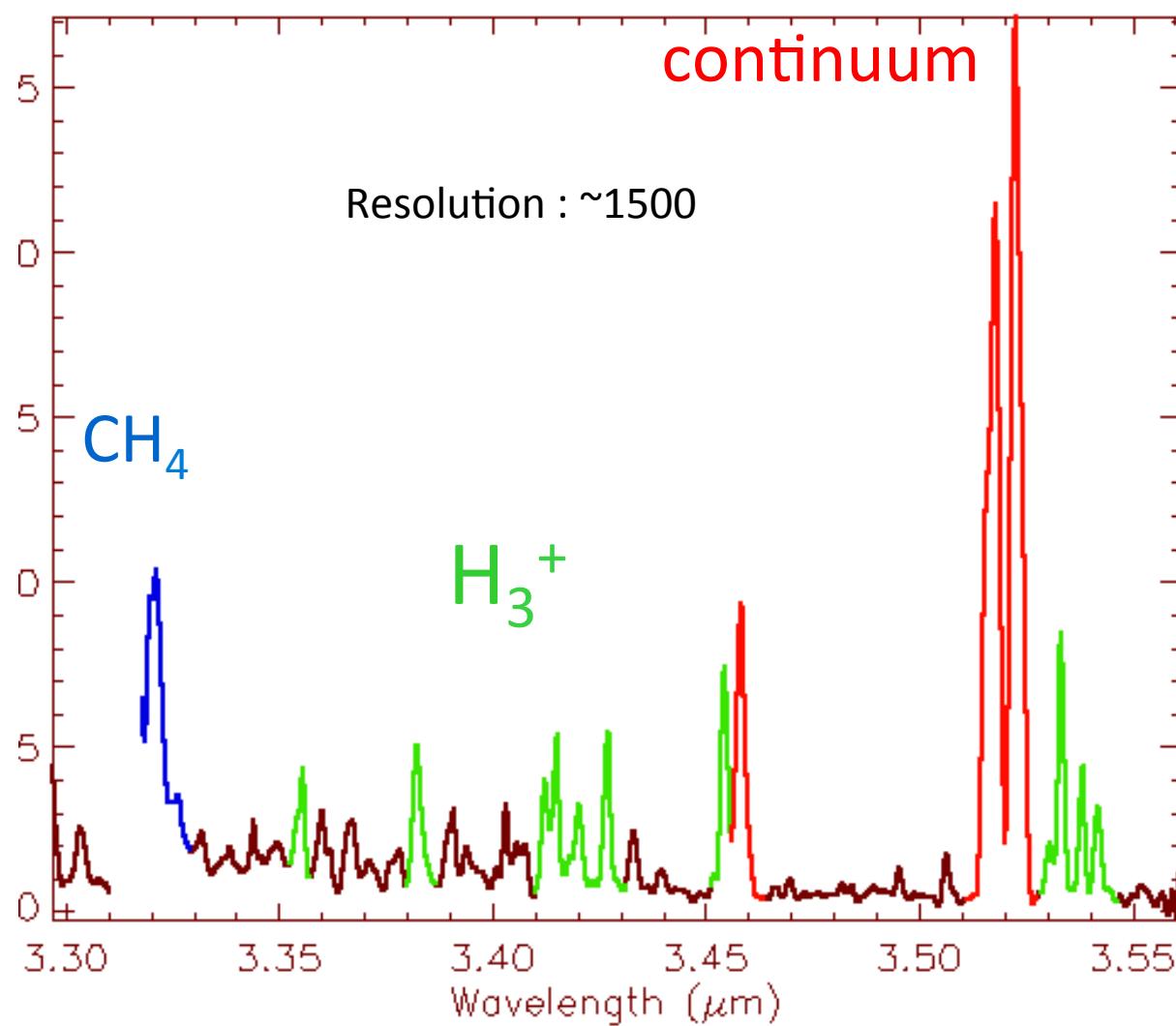
Dynamics

Dynamics is important on all giant planets : composition variations, non – equilibrium species, thermal structure

Dynamics on Exoplanets, and particularly hot Jupiters is probably very different : phase-locked rotation => « Venus-like » circulation, strong stellar wind erosion, etc.



Auroral effects in giant planets



(VLT/ISAAC; P. Drossart, 2004)

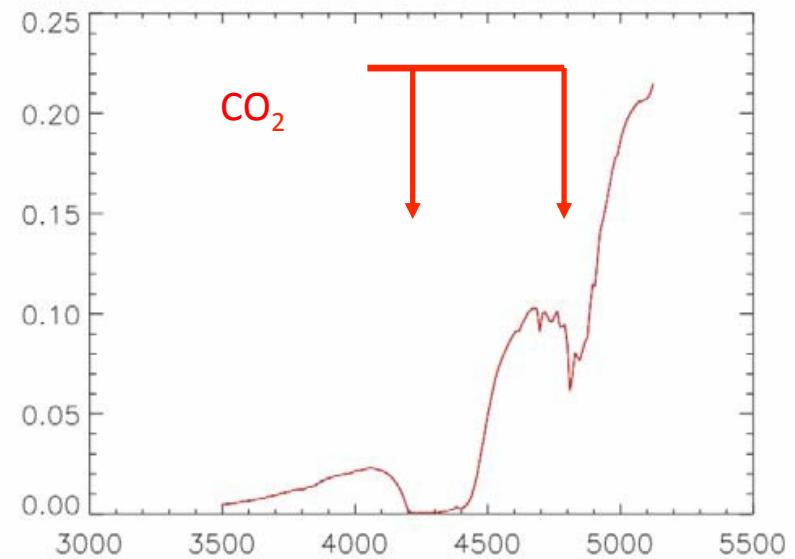
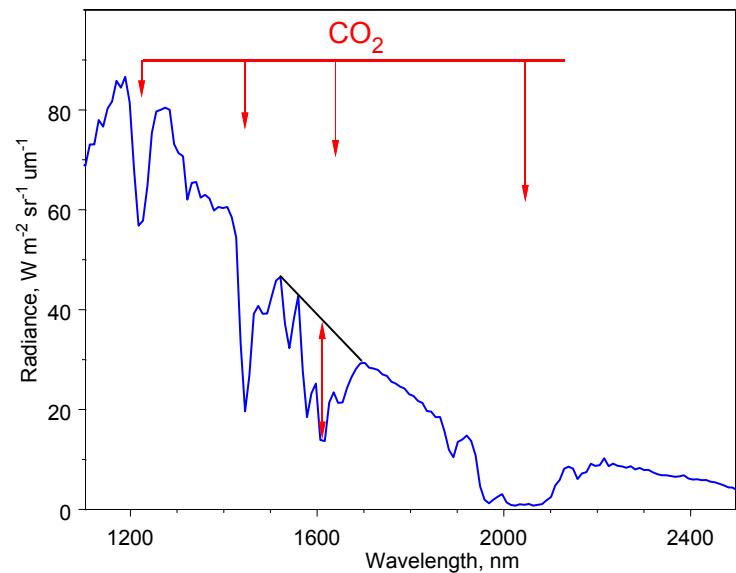
Venus atmosphere

Venus Express observations
Have allowed to quantify the
basic physical parameters in
Venus atmosphere for the
interpretation of :

- Greenhouse effect
- Superrotation
- Mesospheric emissions
(photochemistry and
dynamics)



Venus NIR day side spectrum



Venus Express/VIRTIS spectra in the NIR (day side)

Most of the absorptions : CO₂ !

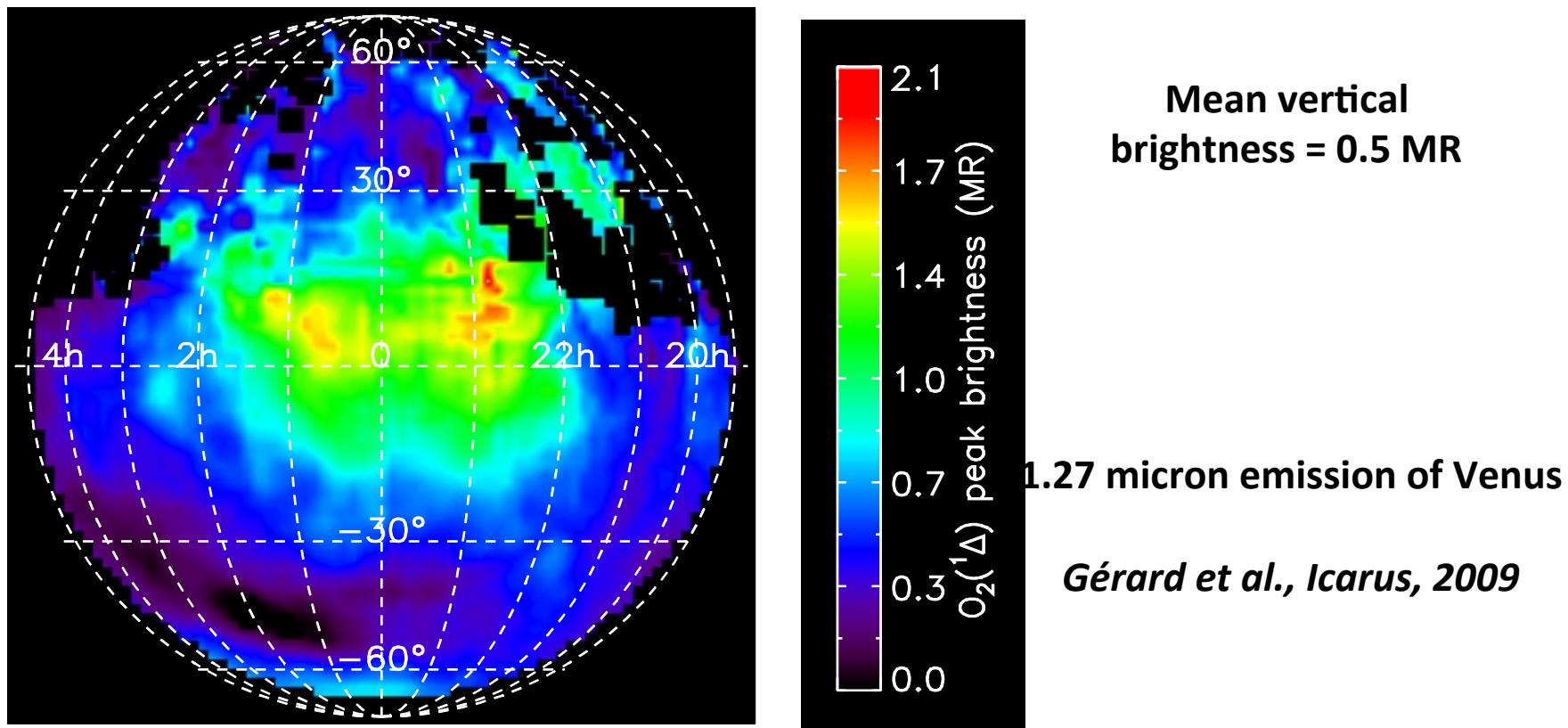
Greenhouse effect

Contribution to greenhouse effects from atmospheric constituents on Venus and Earth

	Venus	Earth
CO ₂	420°C	7°C
H ₂ O	70°C	16°C
Clouds	140°C	8°C
Others	21 °C	0.6°C

Surface temperature, and stability of liquid water strongly dependent on GH amplitude

O_2 intensity : night side emission of Venus at 1.27 micron



List of ingredients for a planet recipes

- Atmospheric composition (gas, clouds)
- Spectroscopy
- Disequilibrium phenomena :
 - Thermodynamics : kinetics
 - Non thermal effects
- Atmospheric Dynamics
- Aeronomy
- Coupling interior / atmosphere
- History

History of planetary atmospheres

Origin : primitive/secondary atmospheres

Evolution : link to volcanic activity

Catastrophic evolution : runaway greenhouse effect

=> Mars and Venus have probably all been habitable at some period of their history

⇒ Earth will probably experiment a runaway GH within 1-2 Gy

⇒ Large uncertainties in the definition of habitable zone

Vibration rotation bands of CO₂ in the infrared

Lopez-Puertas & Taylor,
2001

RT in the infrared : vibration-rotation of molecules : 1) CO₂

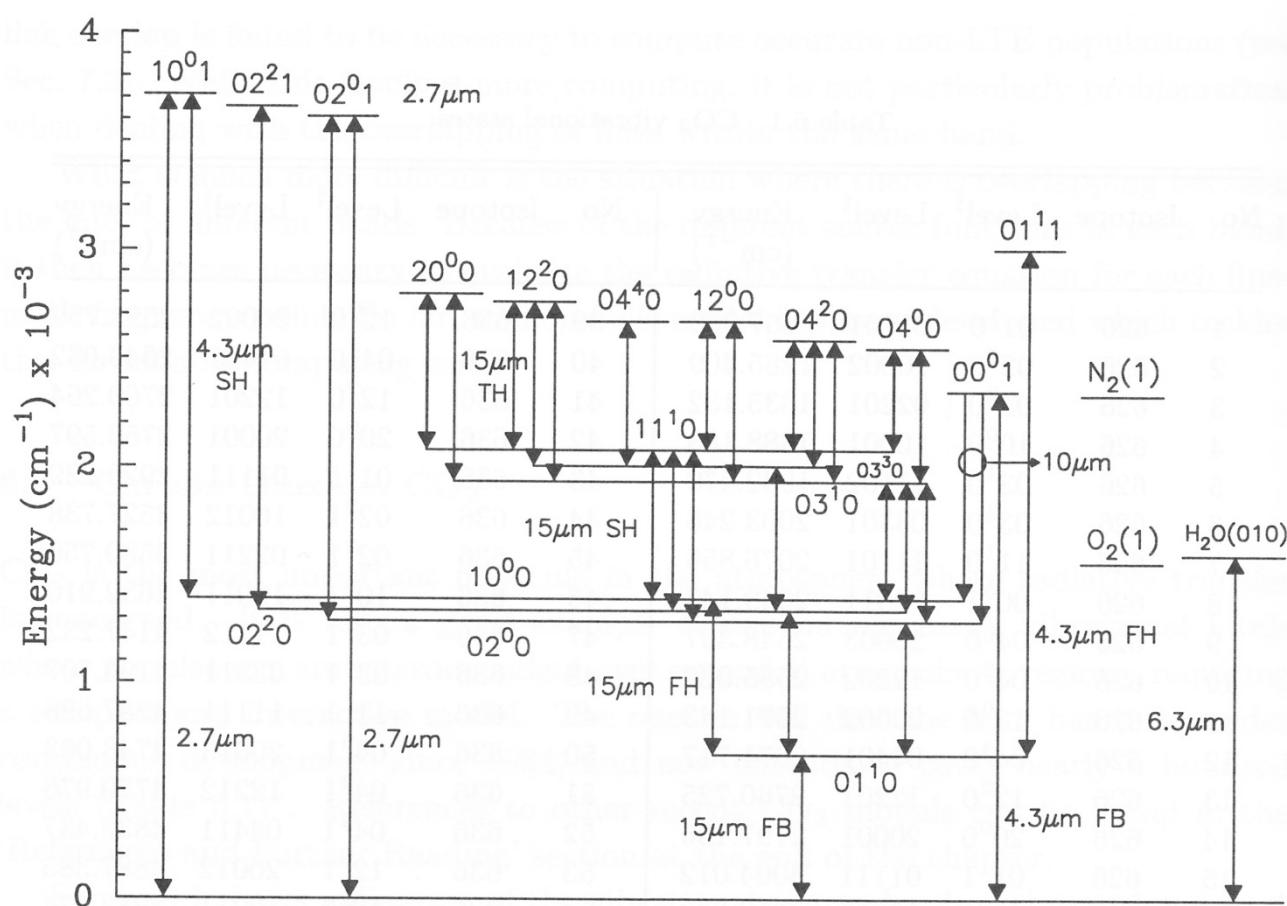
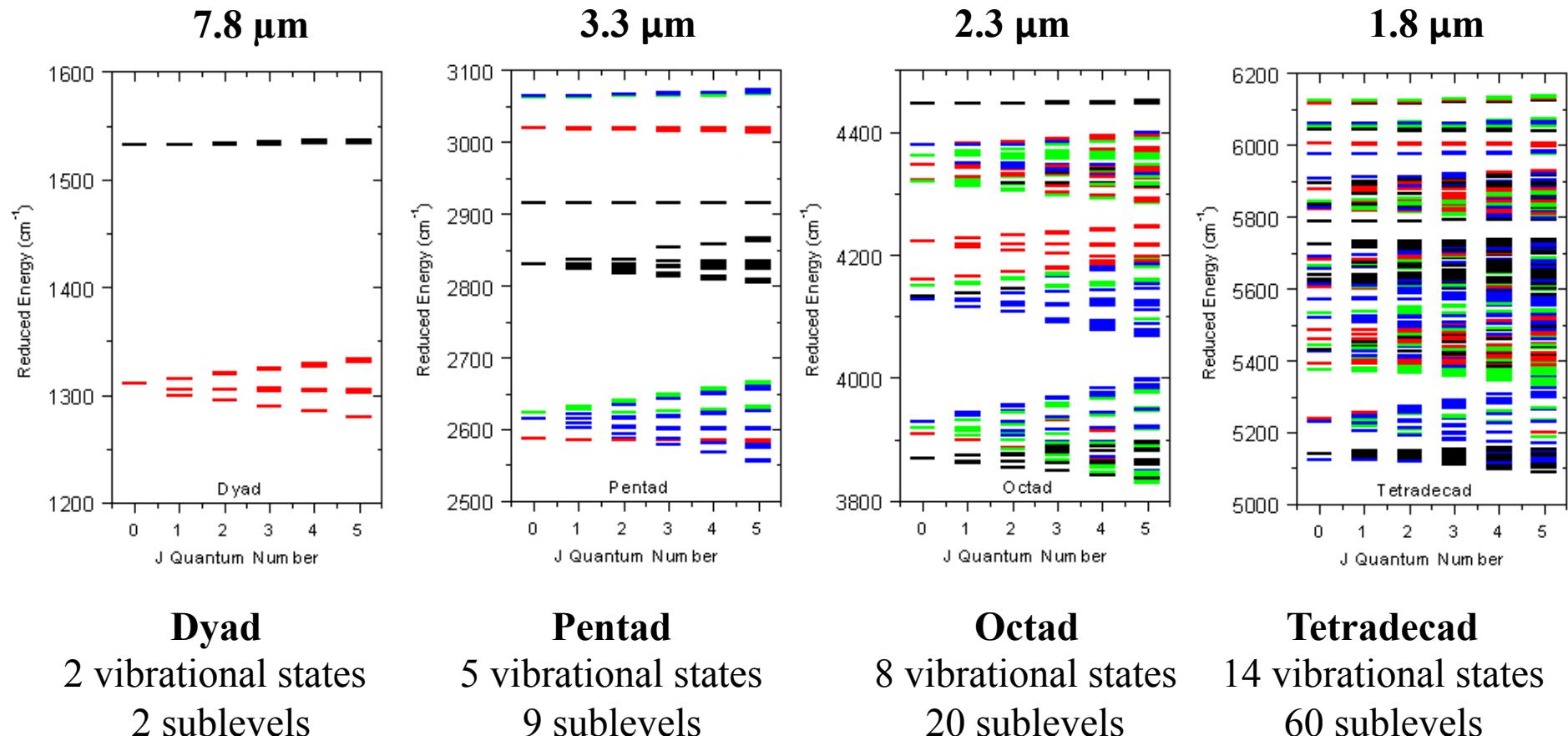


Fig. 6.1 Vibrational levels (with energy lower than 2.7 μm) and transitions for the CO₂ major isotope, and for the first vibrational levels of N₂, O₂, and H₂O.

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vibration/rotation bands: 2) CH_4



Wenger and Champion, JQSRT, 1998

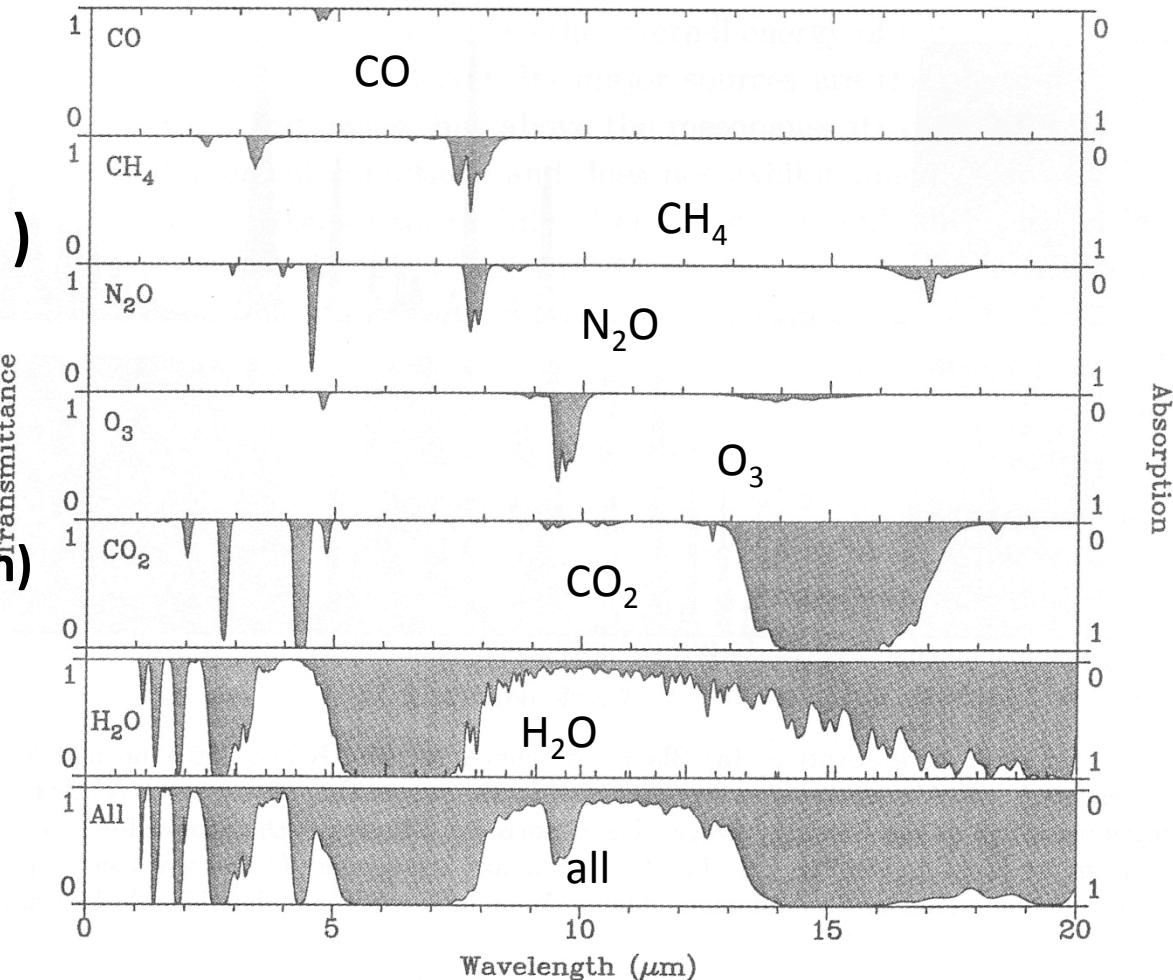
Earth transmittance

Simplified Radiative transfer in planetary atmosphere (neglecting scattering)
 $e_\nu = k_\nu$ in RT eq.

=>No angular dependence in the extinction coefficient (nor in the source function)

All the complexity is in the absorption coefficients = molecular spectroscopy

Lopez-Puertas & Taylor, 2001



Radiative transfer non-LTE scheme

Non-LTE regime:

$$J\nu \neq B\nu$$

Thermal collision time > radiative time

Collisional, chemical processes to be taken into account to calculate the source function

Lopez-Puertas & Taylor, 2001

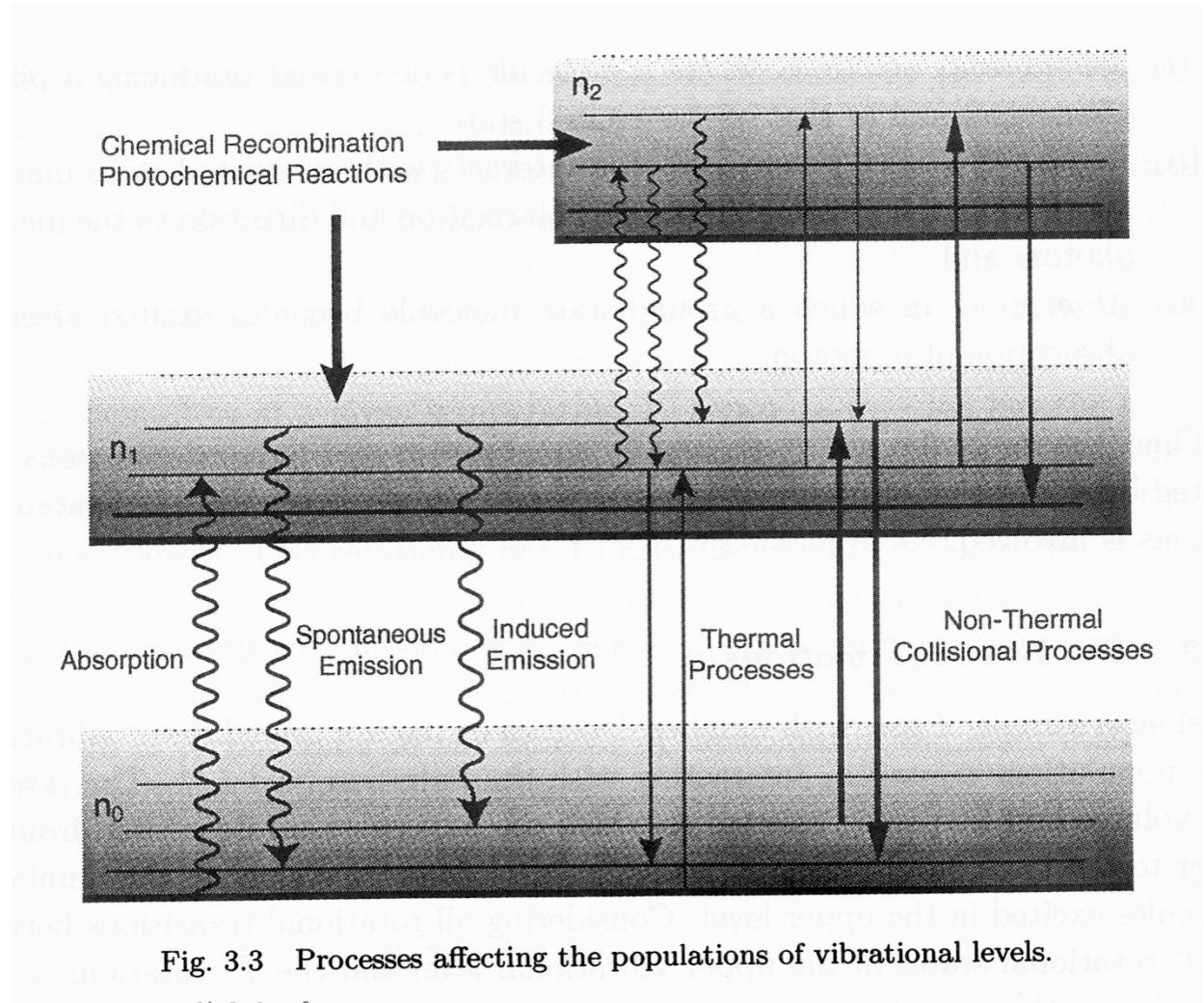


Fig. 3.3 Processes affecting the populations of vibrational levels.

Non-thermal processes

1. Vibrational-vibrational energy transfer.

Example : CO₂ molecule ; exchange with N₂

2. Electronic to vibrational energy transfer.

Example: O(¹D) state exciting the N₂ vibrational modes

3. Chemical recombination or chemiluminescence Example: ozone bands at 10 μm

4. Photochemical reactions

Example : O₂ emissions at 1.27 μm

5. Dissociative recombination (O₂⁺ + e- → O* + O)

6. Collisions with charged particles (auroral processes)

Needs for atmospheric modeling

- Spectroscopy at short wavelengths for major constituents : CO₂, CH₄
- Hot temperatures => hot band spectroscopy for exoplanets
- Minor constituents :
 - H₂O₂, OH, H₂CO for telluric planets
 - NH₃, PH₃, H₂S for giant planets
 - Hydrocarbons and nitriles for Titan
- Line broadening (H₂ for giant planets)
- Relaxation coefficients for non-LTE effects
- line mixing (quantum interferences)
- Collision-induced absorption

Conclusions for exoplanets spectral modeling

Large experience in modeling Earth & planets can be translated in exoplanets modeling

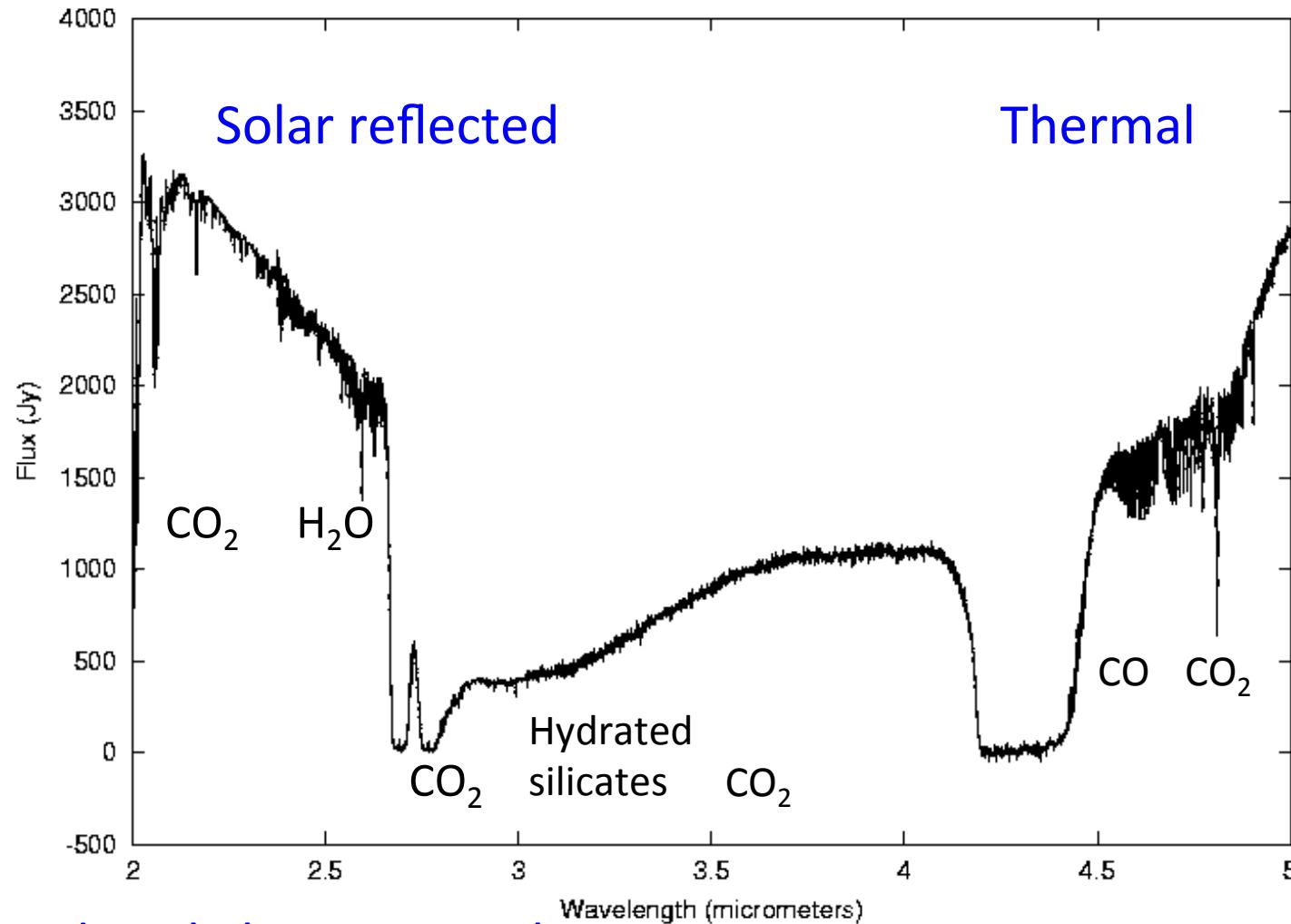
Spectroscopy is the royal avenue to address many physical atmospheric parameters, but

- Complexity must be fully understood (opacities vs line-by-line)
- Non-equilibrium and dynamics effect
- Inversion of parameters not an easy task

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The infrared spectrum of Martian atmosphere



Reflected sunlight -> mineralogy

Thermal emission -> T(z), winds

ISO-SWS Lellouch et al., 2000

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Venus night side spectra

Venus Express / VIRTIS Obs.

