Spectroscopic Parameter Requirements for Remote Sensing of Terrestrial Planets

The four terrestrial (meaning 'Earth-like') planets of our inner Solar System: Mercury, Venus, Earth and Mars. These images were taken by the Mariner 10, Apollo 17 and Viking missions.

Mary Ann H. Smith

NASA Langley Research Center, Science Directorate

Hampton, Virginia 23681-2199, U.S.A.

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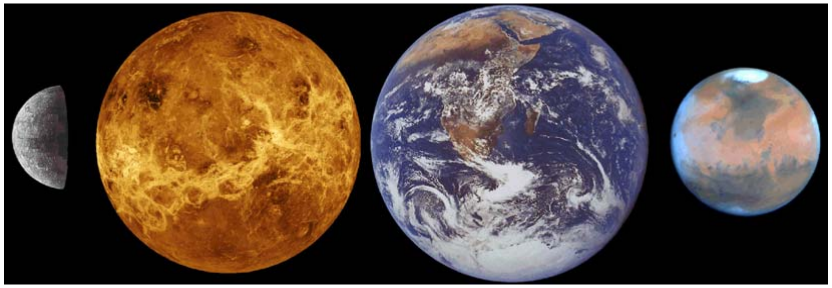
Spectroscopic Issues for the Atmospheres of Terrestrial Planets



1. Expanding line lists to cover near-infrared transitions.
2. Adding parameters for isotopologues.
3. Lower intensity cutoffs to allow more weak transitions to be listed.
4. Adding parameters for broadening and shifts by gases other than air.

Based on talks and conversations at the Chapman Conference on Exploring Venus as a Terrestrial Planet (February 2006) and at the NASA Astrobiology Science Conference (March 2006).

Overview of the Terrestrial Planets

Parameter	Mercury	Venus	Earth	Mars
Mass (Earth = 1)	0.056	0.817	1.000	0.108
Equatorial radius (Earth =1)	0.383	0.949	1.000	0.533
Mean density (kg m^{-3})	5500	5260	5520	3970
Rotation period	58.6 days	−243 days	1 day (24 hours)	24.6 hours
Mean distance from Sun	0.3871 AU	0.7233 AU	1.000 AU	1.5237 AU
Orbital period	88 days	225 days	365 days	687 days
Mean albedo	0.10	0.65	0.37	0.15
Mean surface temperature	~600 K (day), ~100 K (night)	~700 K	288 K	210 K
Mean surface pressure	~1 x 10^{-9} mb	~90 atm	1013.25 mb	7 mb
Major atmospheric constituents	K, Na, O, Ar, He, O_2, N_2, Other	CO_2 97%, N_2 3%	N_2 78%, O_2 21%, Ar 1%	CO_2 95%, N_2 3%, Ar 2%

From Hanel et al., *Exploration of the Solar System by Infrared Remote Sensing* (1992), and other sources.

Current missions and spectrometric sensors observing Mars and Venus

Mars Global Surveyor (NASA)

- TES: Thermal Emission Spectrometer

2001 Mars Odyssey (NASA)

- THEMIS: Thermal Emission Imaging System
- GRS: Gamma Ray Spectrometer

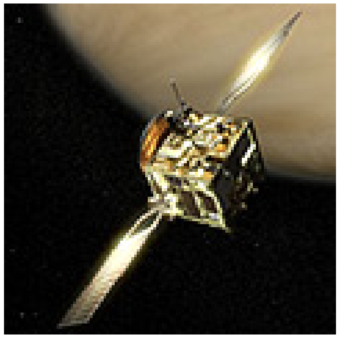
Mars Express (ESA)

- OMEGA: Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité
- PFS: Planetary Fourier Spectrometer
- SPICAM: Spectroscopy for Investigation of Characteristics of the Atmosphere of Mars

Mars Reconnaissance Orbiter (NASA)

- CRISM: Compact Reconnaissance Imaging Spectrometer for Mars
- MCS: Mars Climate Sounder

MRO



Venus Express (ESA)

- VIRTIS: Visible and Infrared Thermal Imaging Spectrometer
- PFS: Planetary Fourier Spectrometer
- SPICAV: Spectroscopy for Investigation of Characteristics of the Atmosphere of Venus

Plus ongoing observations from telescopes based on Earth and elsewhere!

*** Hot Scientific Issues ***

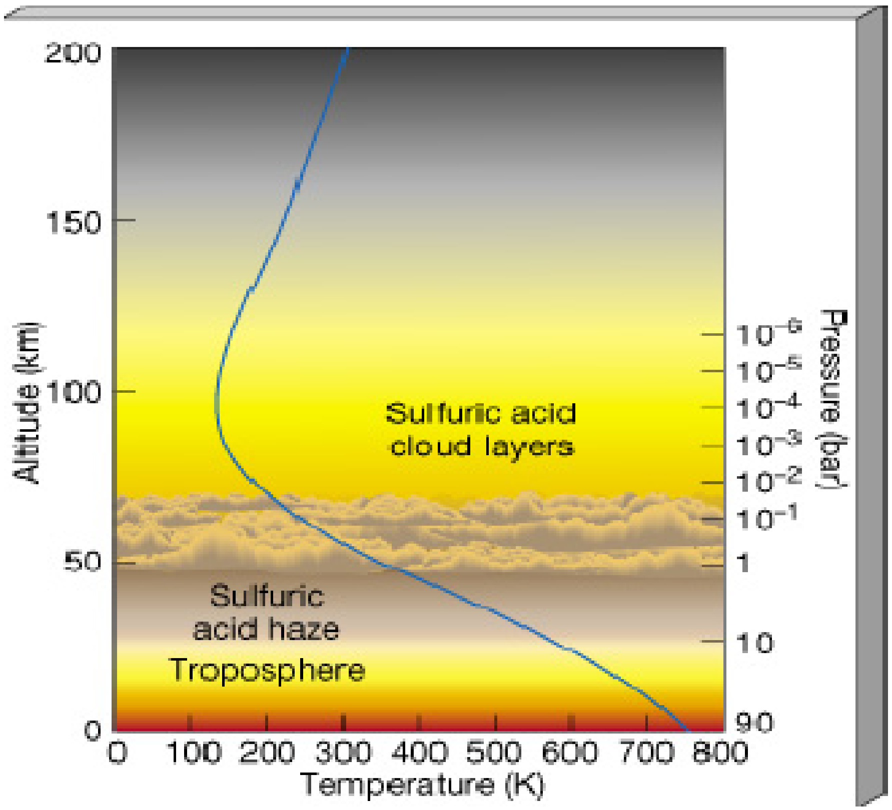
Venus Sulfur Cycle and Surface Chemistry

- Evidence for past or present volcanism?
- What’s going on in the multiple cloud layers?

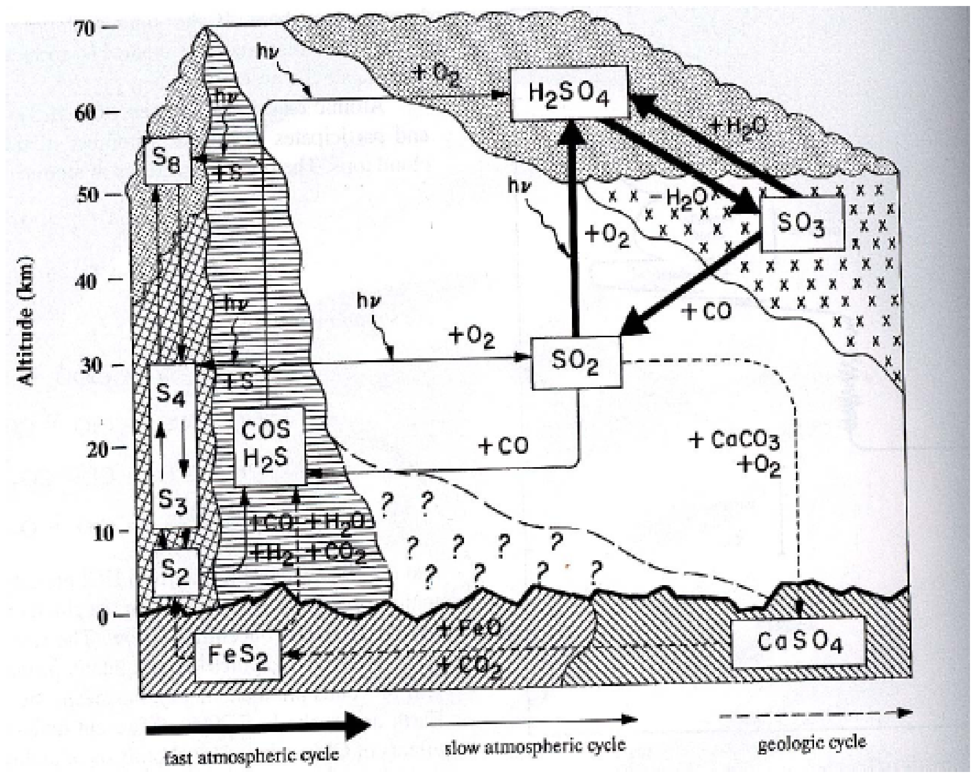
Martian Methane

- How much is there?
- Where does it come from?

Venus has a very complex atmosphere!

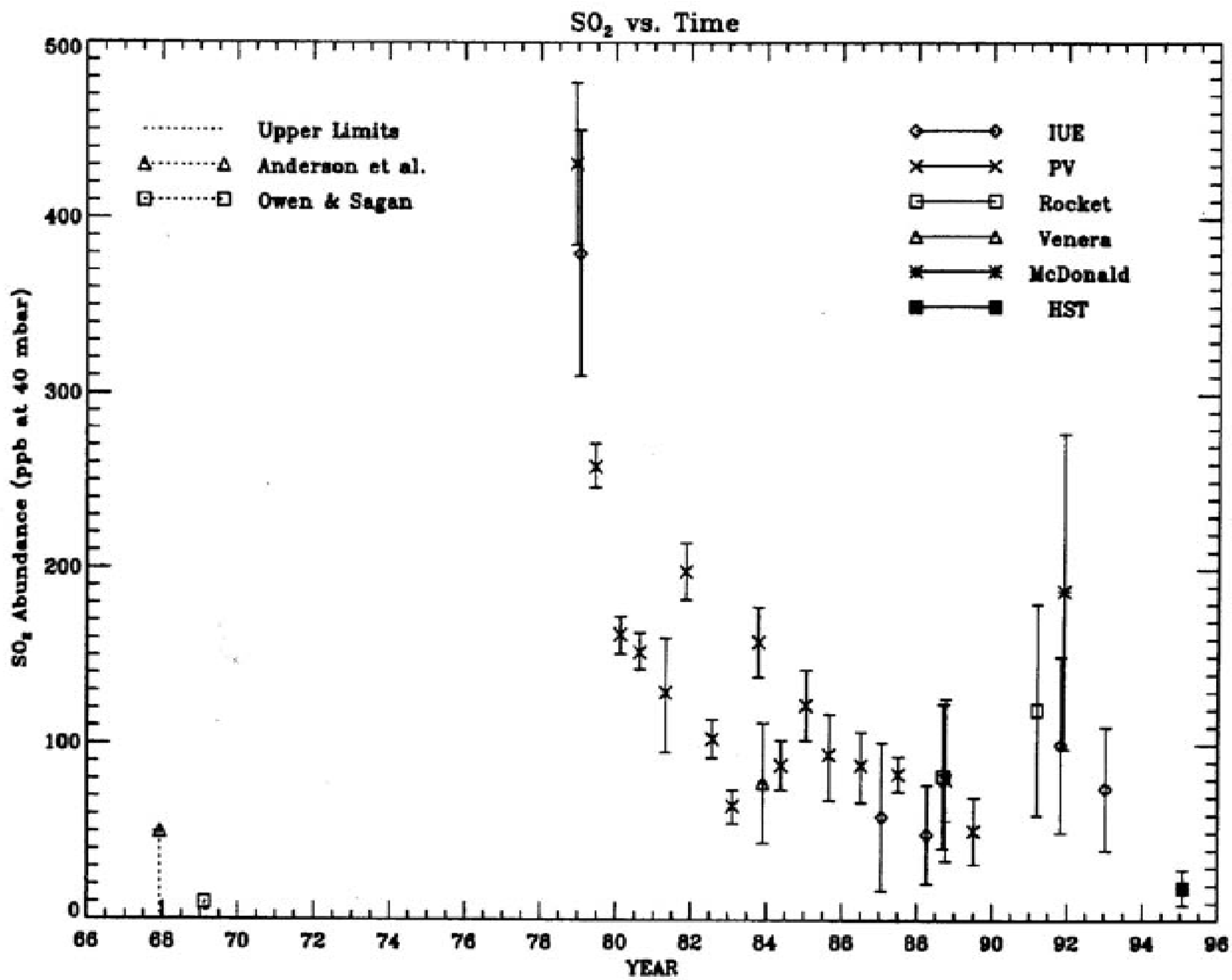


Model Venus temperature profile



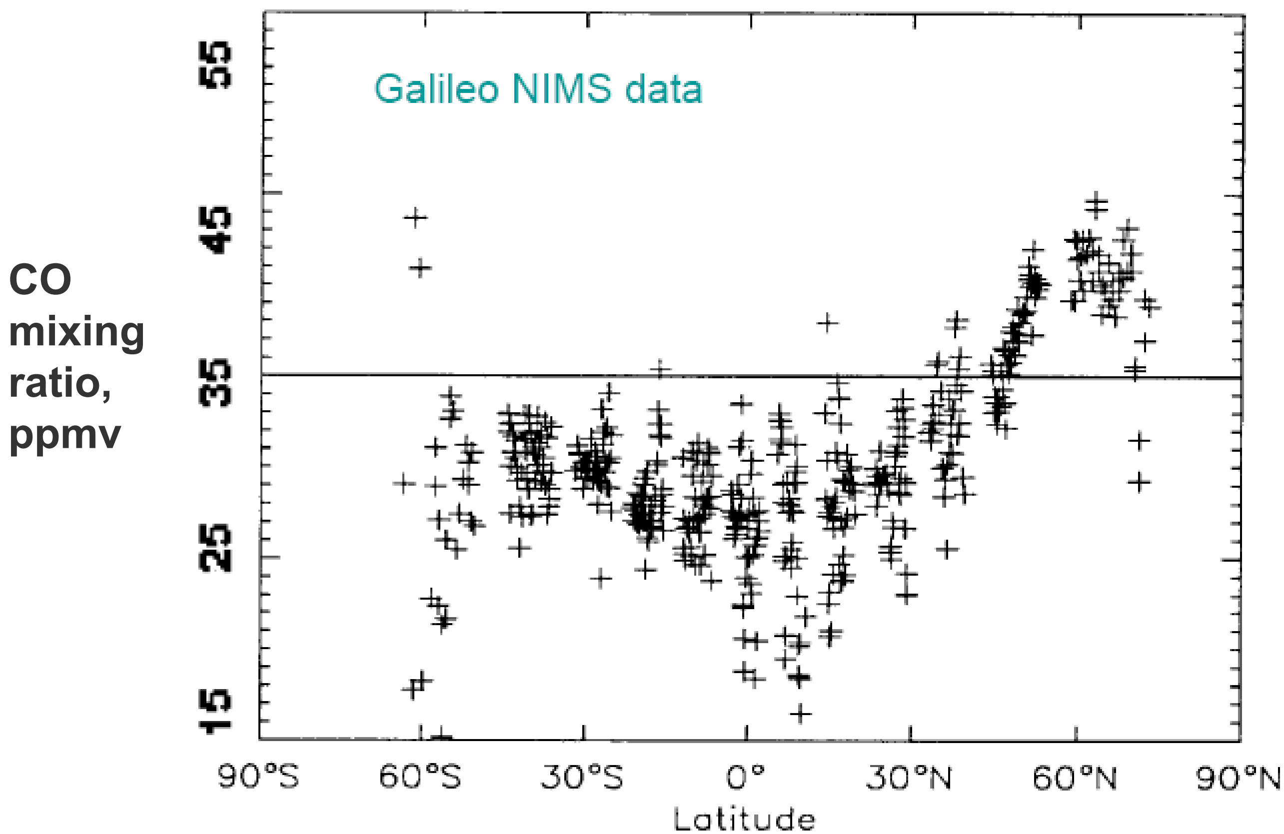
From *Physics and Chemistry of the Solar System*, by John S. Lewis (1997)

Measurements of Venus SO_2 column abundances have varied with time!



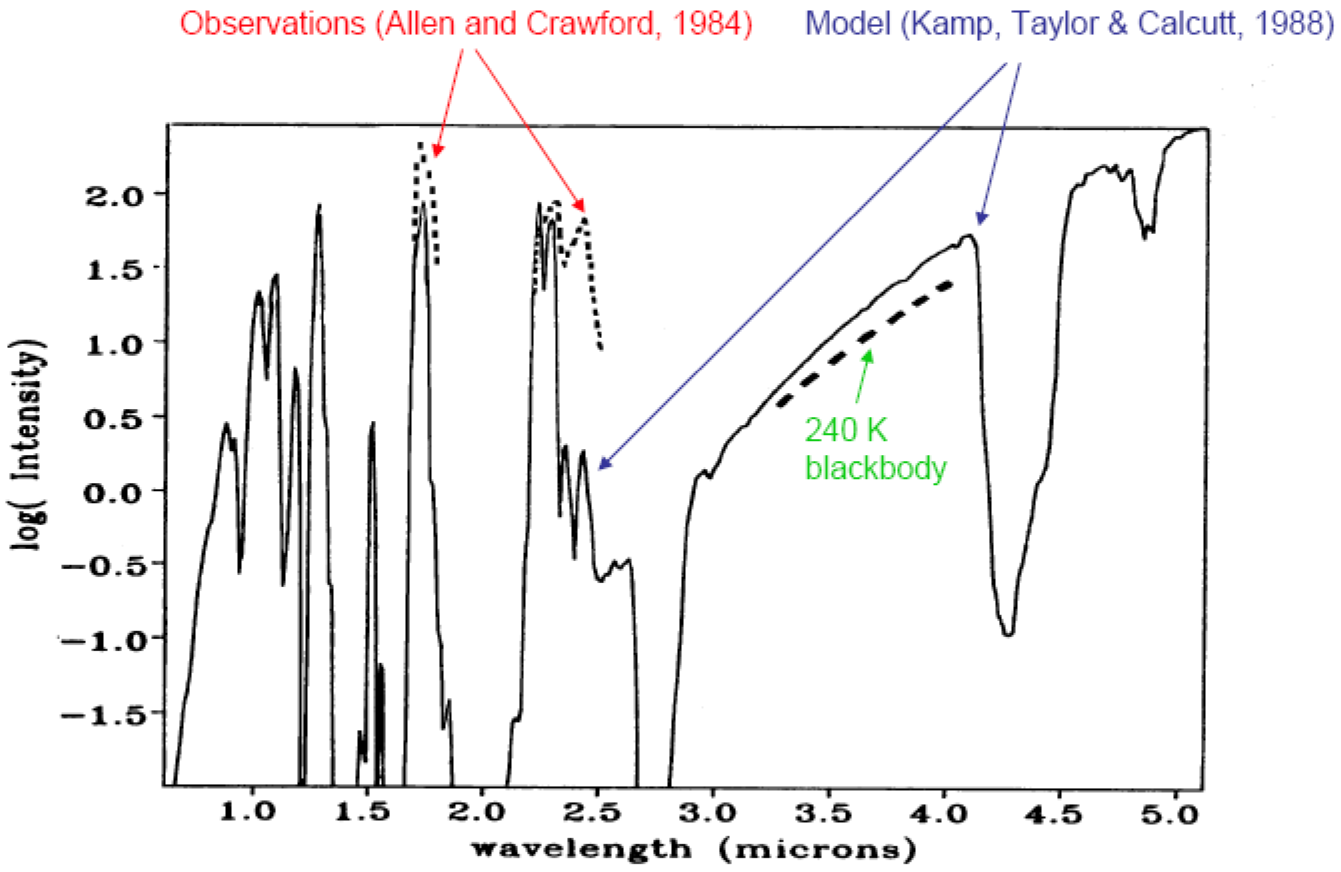
(Figure from Na and Esposito, 1997)

Other Venus atmospheric species also vary.



The variation with latitude of carbon monoxide abundance near 30 km altitude (Collard et al., 1993).

Venus Near-IR Spectrum (from F. Taylor)



Near-IR windows reveal the deep atmosphere of Venus

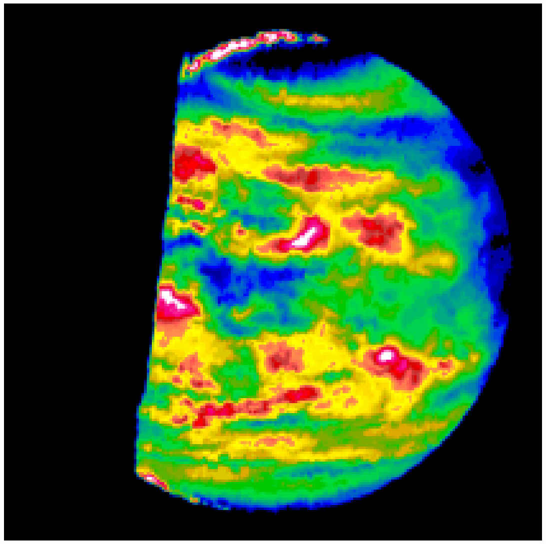


Image of Venus (night side) at 2.3 μm, taken by Galileo (Carlson et al, 1991). The thermal emission from the deep atmosphere is modulated by the cloud structure of the deeper atmosphere. Cloudy regions appear in blue (lower emission), when bright regions (in red) correspond to less cloudy regions.

Synthetic spectrum of Venus night side at the spectral resolution of VIRTIS-H. The unit of radiance is in μW $cm^{-2}sr^{-1}\mu m^{-1}$ (Drossart and Piccioni, 2002).

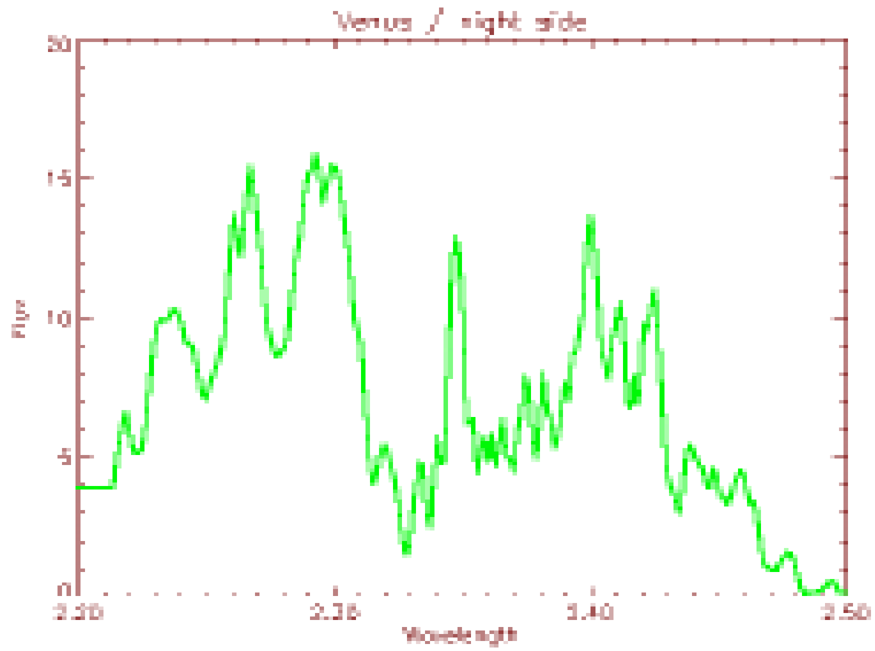
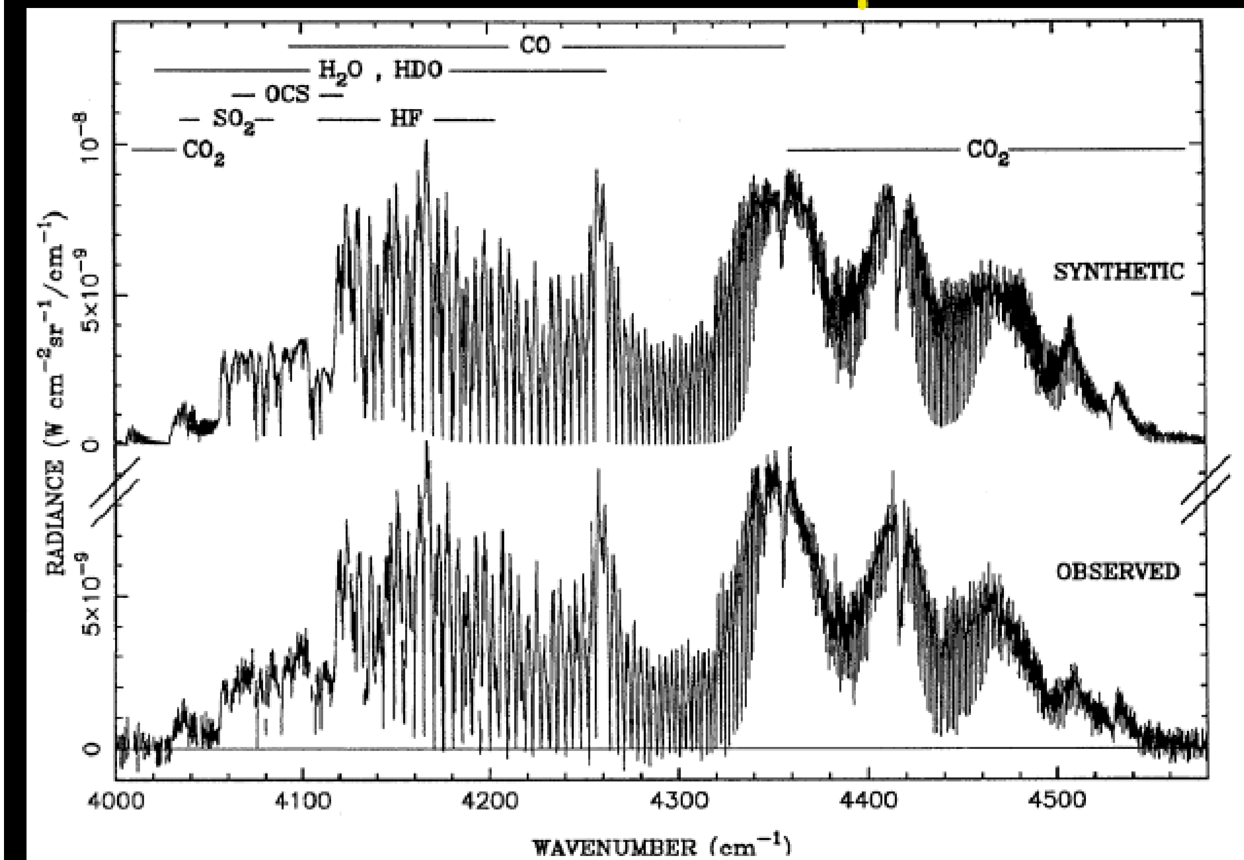


Table 1. Expected parameters of the measurements of the atmospheric composition below the clouds by VIRTIS-H and -M (for wavelength shorter than 2μm)

Trace gas	Wavelength, μm	Altitude,km
H_2O	1.1- 1.18	0-12
	1.74	20
	2.40-2.43	33
HDO	2.38-2.46	33
CO	2.3	30-40
COS	2.43	30-40
SO_2	2.46	40

See the newest images of Venus at http://www.esa.int/SPECIALS/Venus_Express/index.html

Venus nightside windows: 2.3 μm



CFHT/FTS observations
Res = 0.15 cm^{-1}

(Bézard *et al*. 1990, Taylor *et al*. 1997)

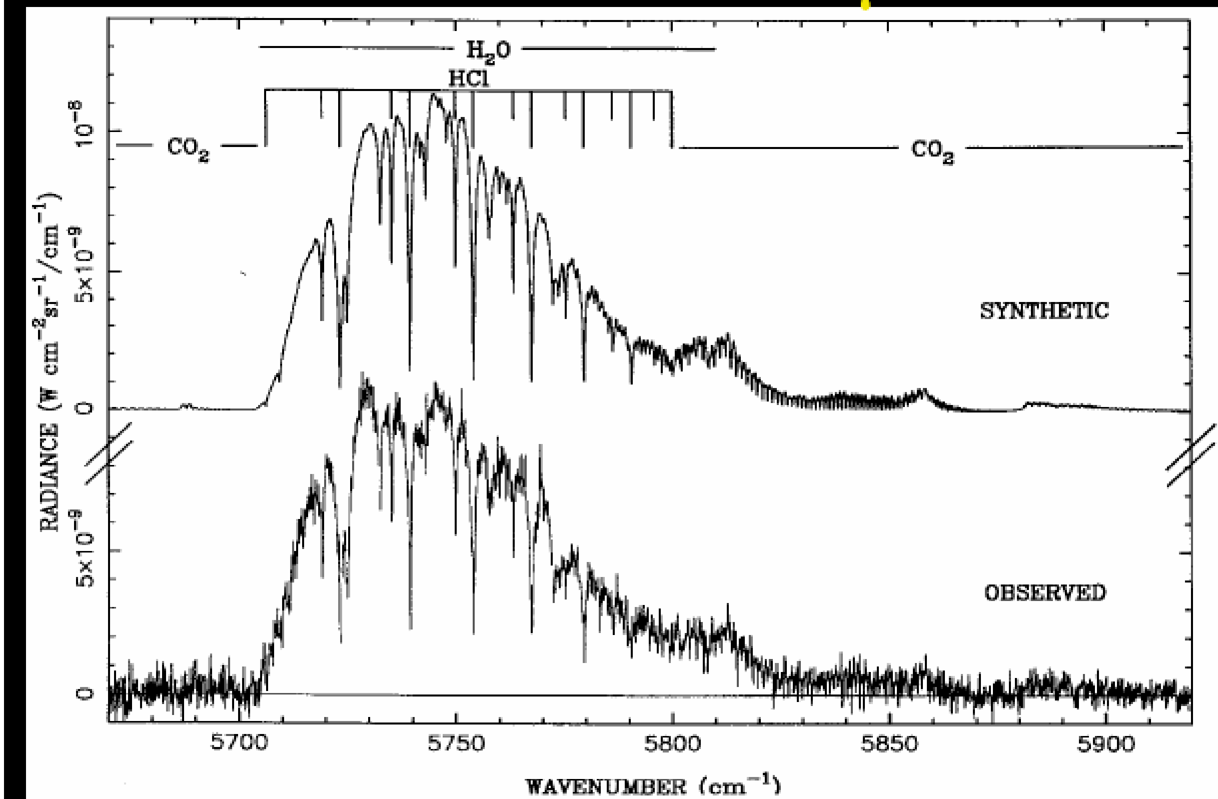
Altitude range probed:
26-45 km

14/02/06

Exploring Venus as a terrestrial planet

High-resolution Venus spectra from Earth-based telescopes (Bézard, 2006)

Venus nightside windows: 1.74 µm



CFHT/FTS observations
Res = 0.15 cm^{-1}

(Bézard *et al*. 1990, Taylor *et al*. 1997)

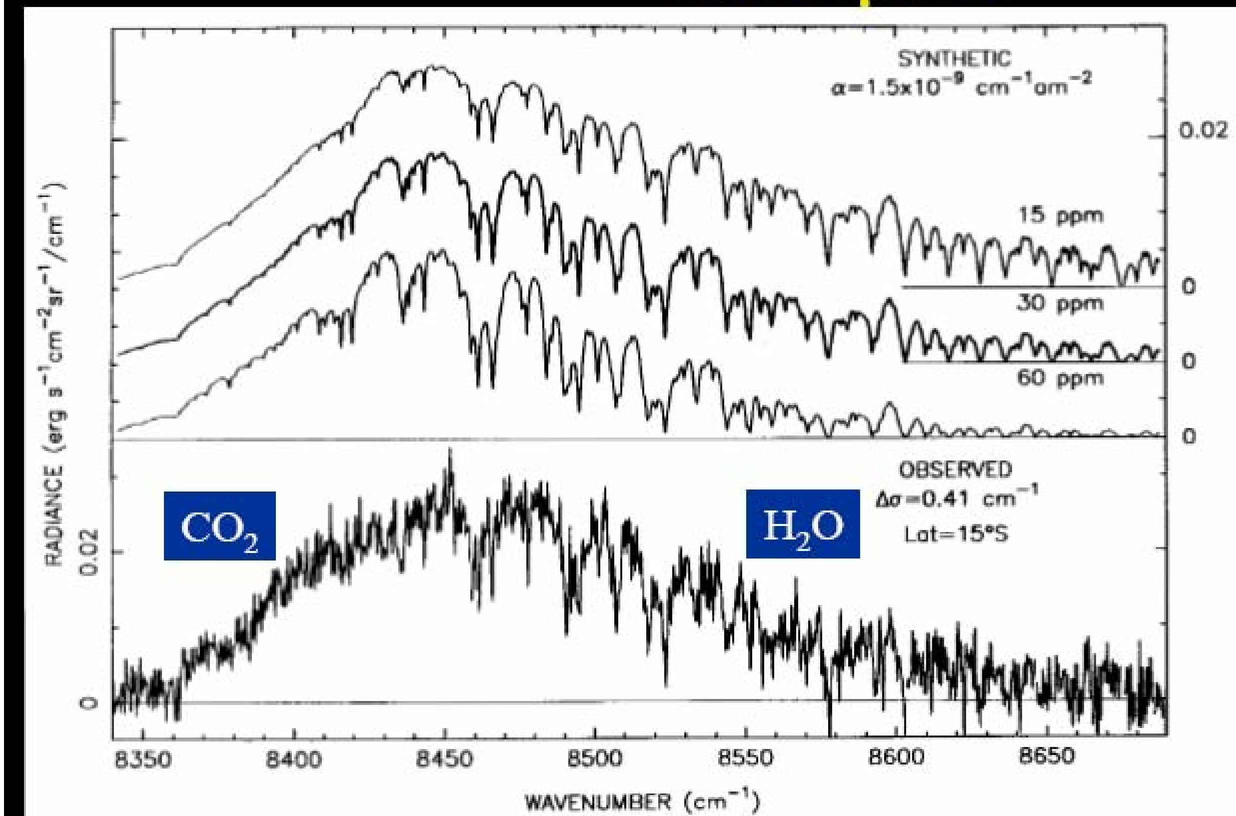
Altitude range probed:
15-30 km

14/02/06

Exploring Venus as a terrestrial planet

High-resolution Venus spectra from Earth-based telescopes (Bézard, 2006)

Venus nightside windows: 1.18 μm



CFHT/FTS observations
Res = 0.41 cm^{-1}

(de Bergh *et al.* 1995)

Altitude range probed:
0-15 km

14/02/06

Exploring Venus as a terrestrial planet

High-resolution Venus spectra from Earth-based telescopes (Bézard, 2006)

The New York Times
nytimes.com

March 29, 2005

Life on Mars? Could Be, but How Will They Tell?

By KENNETH CHANG

The landscape looked lifeless. But satellite images from orbit identified geological formations containing minerals that microbes sometimes like to nestle in, and scientists dispatched a small rover to look at the rocks up close.

…

"You've got to go look," said Dr. Alan S. Waggoner, director of the Molecular Biosensor and Imaging Center at Carnegie Mellon University in Pittsburgh and a participant in the NASA-sponsored project. "I'd give it a 50-50 shot that you could find it somewhere underground. But then that's a guess."

He is not alone. In an informal poll taken last month at a conference in the Netherlands, three-quarters of 250 scientists working on the European Space Agency's Mars Express mission said they believed Mars once possessed conditions hospitable to life. One quarter believe it still does.

Planetary scientists have long thought that early in its history Mars may have been more like Earth, warm and wet, a place where life could have taken hold. But then the climate turned cold and dry and has remained cold and dry for several billion years. For many, the presumption was that Martian life, if any ever existed, died away long ago.

Over the past year, the notion that life not only arose on Mars but persists today has become more plausible with reports of methane gas currently floating in its atmosphere. The two most likely sources are geothermal chemical reactions or bacteria, and because ultraviolet light breaks down methane within a few centuries, any detectable methane must have been put there recently.

Another possibility is that the methane comes from the remains of long dead organisms trapped underground as oil or coal-like deposits and transformed to methane by the heat of meteor impacts.

Martian Methane Issues

Mars Express PFS detected methane above areas of the Martian surface where there also appears to be subsurface ice (Formisano et al., 2004). Observed methane concentrations vary from 0 to 30 ppbv.

Earth-based spectroscopy with the CFHT telescope also finds an average Martian methane concentration of 10 ppbv (Krasnopolsky et al., 2004).

Observations of Mars with the Gemini South telescope (Mumma et al., 2005) found much higher methane concentrations (up to 250 parts per billion) in some equatorial regions.

SCIENCE, VOL 309, p. 1984, 23 SEPTEMBER 2005

Why the disagreement?

Martian Methane Challenges, Part 1

Low CH_4 concentrations → Weak features, even in the v_3 fundamental band!

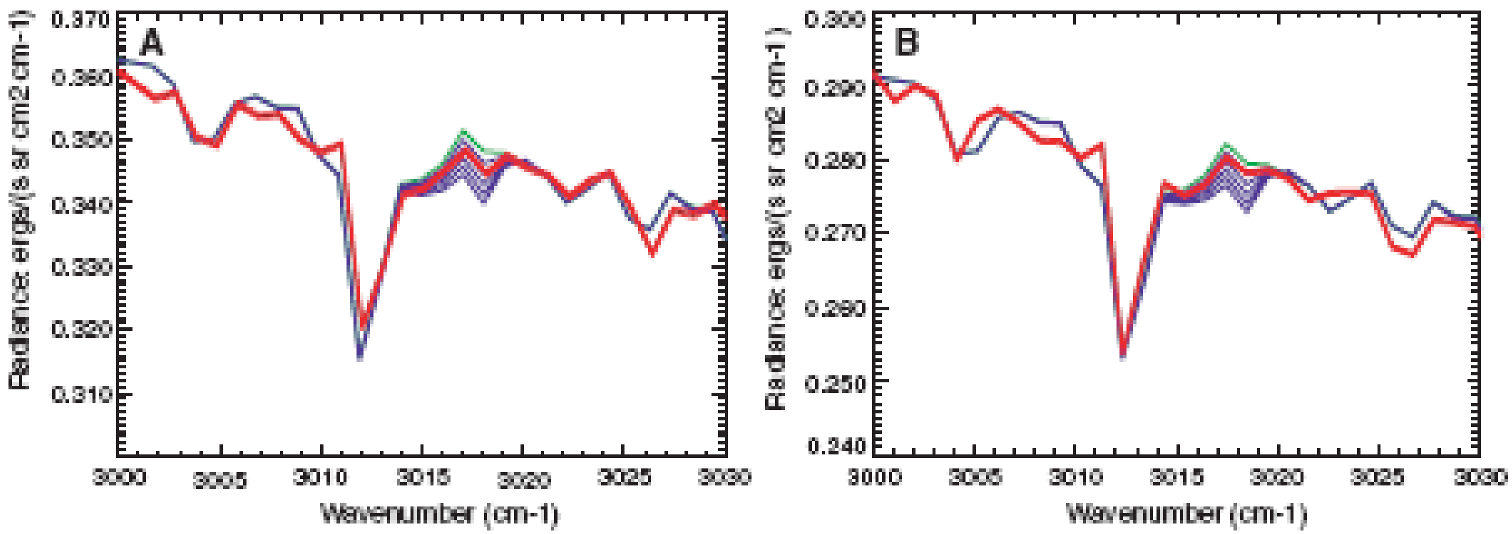


Fig. 2. (A) Synthetic spectra computed for 0 ppbv (green curve) and 10, 20, 30, 40, and 50 ppbv (violet curves) of methane, compared with the PFS average spectrum (black curve). The synthetic spectra have been computed for 6.7 millibars of CO_2, including 350 ppm of H_2O, along with dust and water ice clouds. The temperature profile obtained from simultaneous measurements in the thermal radiation was used. (B) Same as (A), with the PFS mean spectrum shown in Fig. 1B.

Note that the feature growing in the series of violet curves is the v_3 Q branch.

Figure from Formisano et al. (2004).

A is Jan.-Feb. 2004 averaged spectrum; B is May 2004 averaged spectrum.

Martian Methane Challenges, Part 2

Earth-based measurements must account for strong terrestrial CH_4 features!

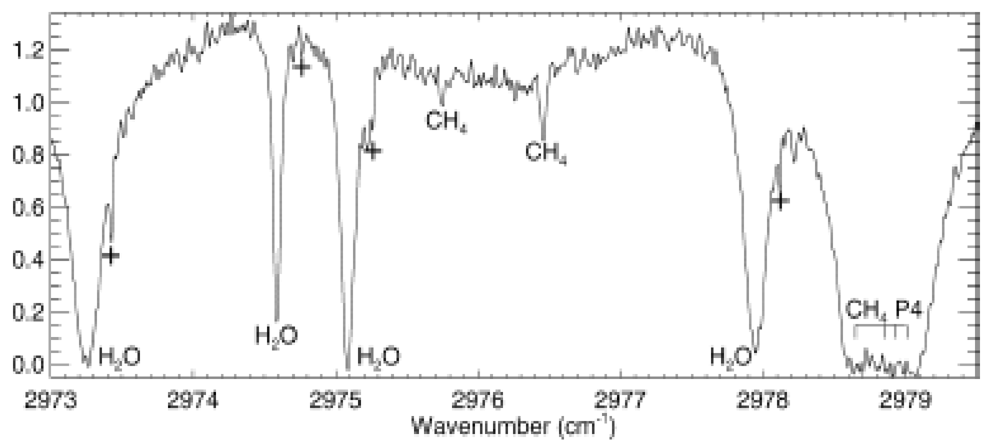


Fig. 1. A small part (3%) of the CFHT/FTS spectrum of Mars. Telluric lines of CH_4 and H_2O are the major features in the spectrum. Martian H_2O line (crosses) are weak, narrow, and shifted to the blue by 0.1762 cm^{-1}.

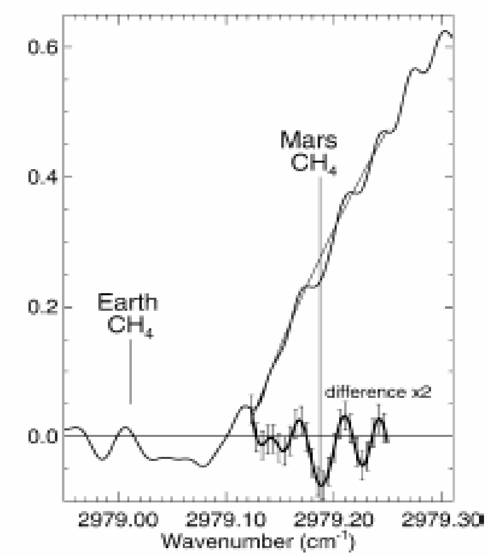


Fig. 3. Blue wing of the strongest methane telluric line in our spectrum. The expected positions of the line center and the Doppler-shifted martian line are shown. 75 points near the martian line are fitted by a cubic parabola (thin line). Difference between the measured points and the fitting is also shown. The greatest difference is exactly centered at the expected position of the martian line, is of the proper sign, and exceeds the other minima and maxima by more than a factor of 1.8.

Figures from Krasnopolsky et al. (2004)

Martian Methane Challenges, Part 3

Could products of CH_4 decomposition or reaction complicate the spectroscopic picture in the 3 μm region?

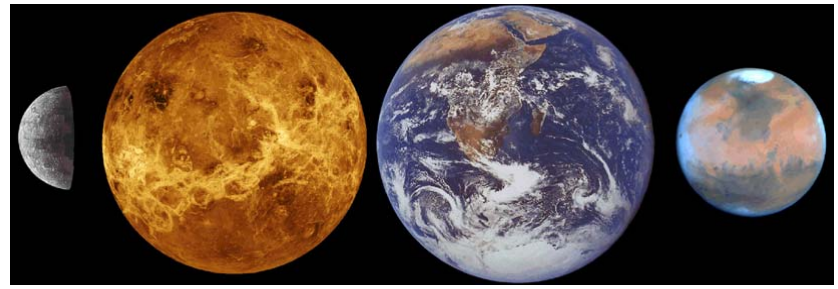
Possible Martian candidates: CH_3OH, H_2CO, HDCO

What about interference from terrestrial molecules with strong transitions in the C-H stretch region?

How well can we model the details of the 3-μm CH_4 spectrum, including isotopologues?

Some Martian sensors "on the drawing board" desire to use near-IR bands to measure CH_4. How well do we know these bands?

Spectroscopic Issues for the Atmospheres of Terrestrial Planets



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HITRAN Gaps for Venus

- **Parameters for SO, H_2SO_4, and some other species and isotopologues of interest for Venus.**
- **Parameters for transitions in the near-IR windows.**
- **Halfwidth and shift parameters for CO_2-broadening of H_2O, CO, SO_2, HF, HCl, etc.**
- **Halfwidth temperature-dependence exponents valid for high and low temperatures.**
- **Line-mixing parameters for CO_2 and possibly other species.**

HITRAN Gaps for Mars

- Parameters for some species of interest (e.g., proposed breakdown products of CH_4).
- Parameters for isotopologues involving ^{12}C, ^{13}C, ^{16}O, ^{18}O, D, H, etc. (e.g., $^{13}CH_4$ and CH_3D in the near-IR)
- Broadening and shift parameters for CO_2-broadening of H_2O, CO, CH_4, etc.
- Accurate air-broadening and shift coefficients and line mixing parameters for terrestrial transitions that interfere with Earth-based observations of Martian spectra (e.g., H_2O, CH_4).
- Halfwidth temperature-dependence exponents valid over Martian and terrestrial temperature ranges.

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