Solar Occultation FTIR at Mars: A Space Odyssey for 2011?

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The Big Questions

- Does life exist on Mars today? If not, was it ever present?
- Why is the surface so young? Is intrusive volcanism still ongoing?
- What happened to the volatiles? Where did all the carbon go? Where is the H_2O?

Can solar occultation spectroscopy answer these questions without the risk and expense of landing on the surface?

The Martian Atmosphere

- Surface pressure: ~6.4 mbar (4.0 to 8.7 mbar depending on season)
- Surface temperature 150-280K
- Scale height: 11 km
- Trace gas composition: mostly ignorance

CO_2	~95%
N_2	2.7%
Ar	1.6%
O_2	0.13%
CO	0.08%
H_2O	210 ppmv
NO	100 ppmv
Ne	2.5 ppmv
Kr	0.3 ppmv
Xe	0.08 ppmv
CH_4	0.02 ppmv ?

How do we know the composition of the Mars atmosphere?

Earth-based observations of Mars using large telescopes

Mars-orbiting low spectral resolution nadir-pointing instruments
 using thermal emission (e.g. THEMIS)
 using reflected sunlight (e.g. PFS)

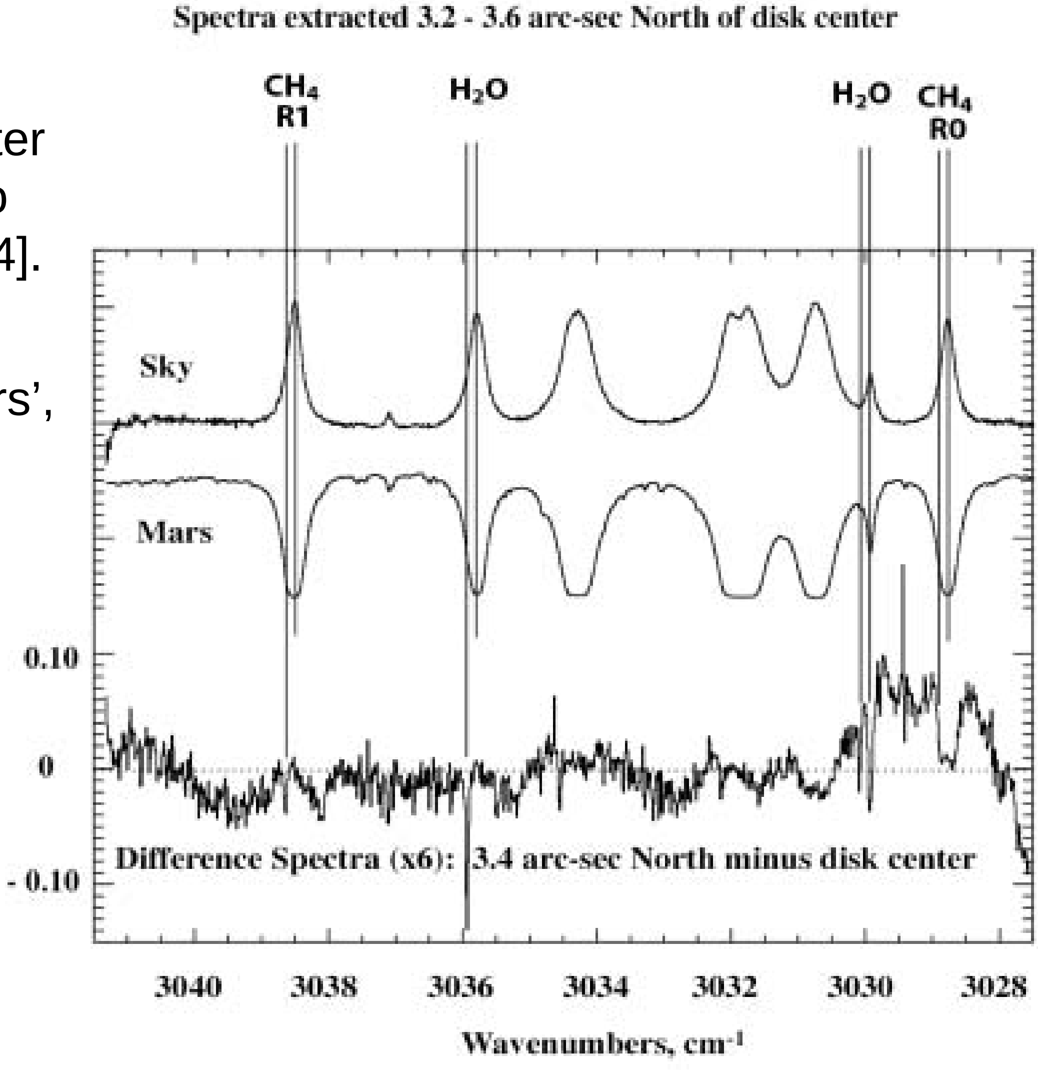
Solar/stellar occultation in the NIR/Vis/UV (SPICAM, Mars Express)

No high-resolution, mid-IR solar occultation experiment has ever been sent to Mars

Earth-based Measurements

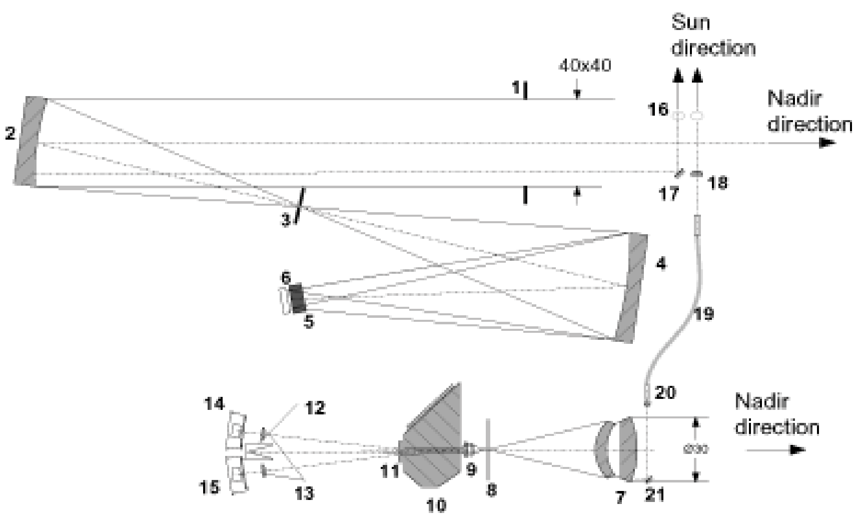
Detection of CH_4 in the Martian atmosphere from ground-based spectra from Phoenix spectrometer at Gemini South telescope, Cerro Tololo, Chile, [*Mumma et al,* 2004].

Earth's atmosphere contains 10^4 times more CH_4 column than Mars', making detection of Martian CH_4 difficult, even with a substantial Earth-Mars doppler shift.



Mars Express

- ESA's Mars Express arrive at Mars early 2004.
- SPICAM, a NIR/UV/Vis instrument will measure ozone and other trace gases in the UV by solar/stellar occultation.

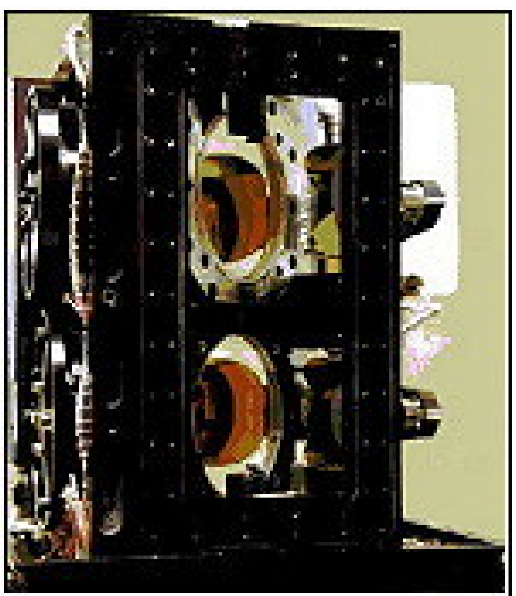


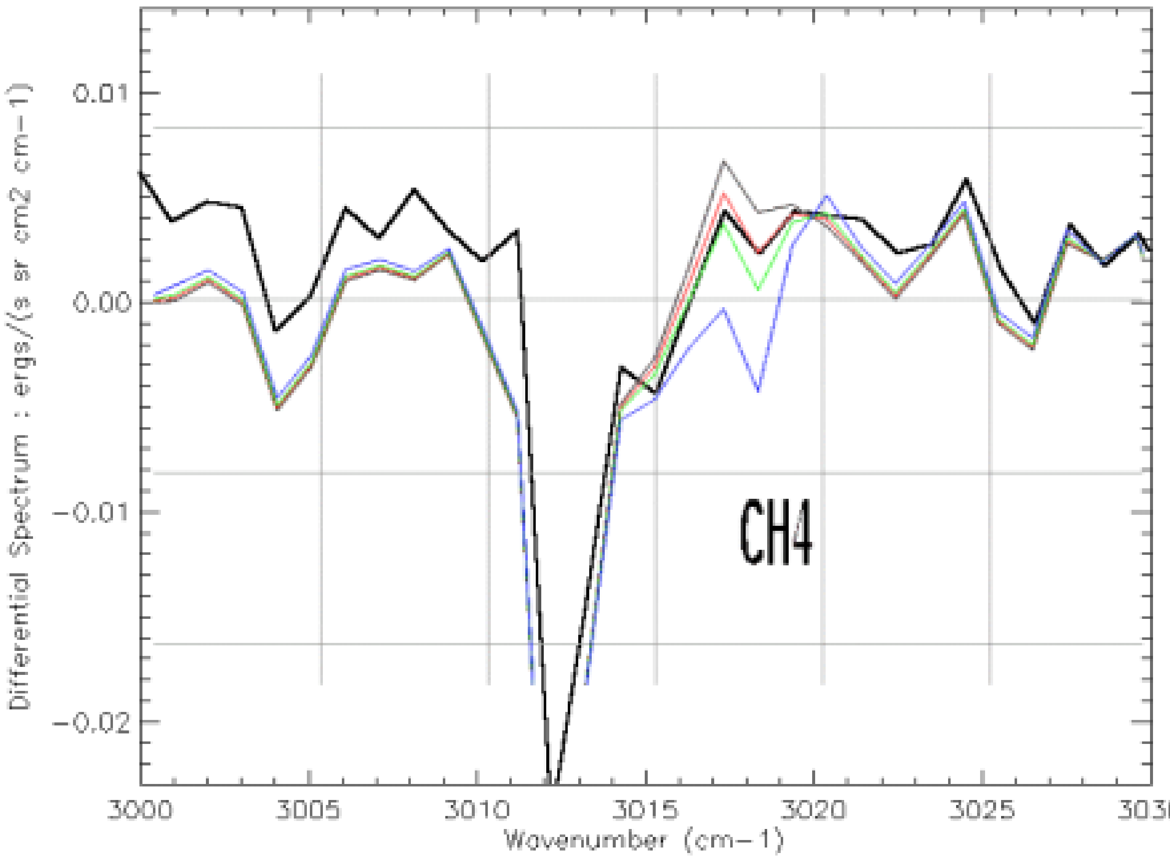
Planetary Fourier Spectrometer (PFS)

1.4 cm^{-1} spectral resolution FTIR looking at reflected IR sunlight.

CH_4 detection [Krasnopolsky et al. 2004]

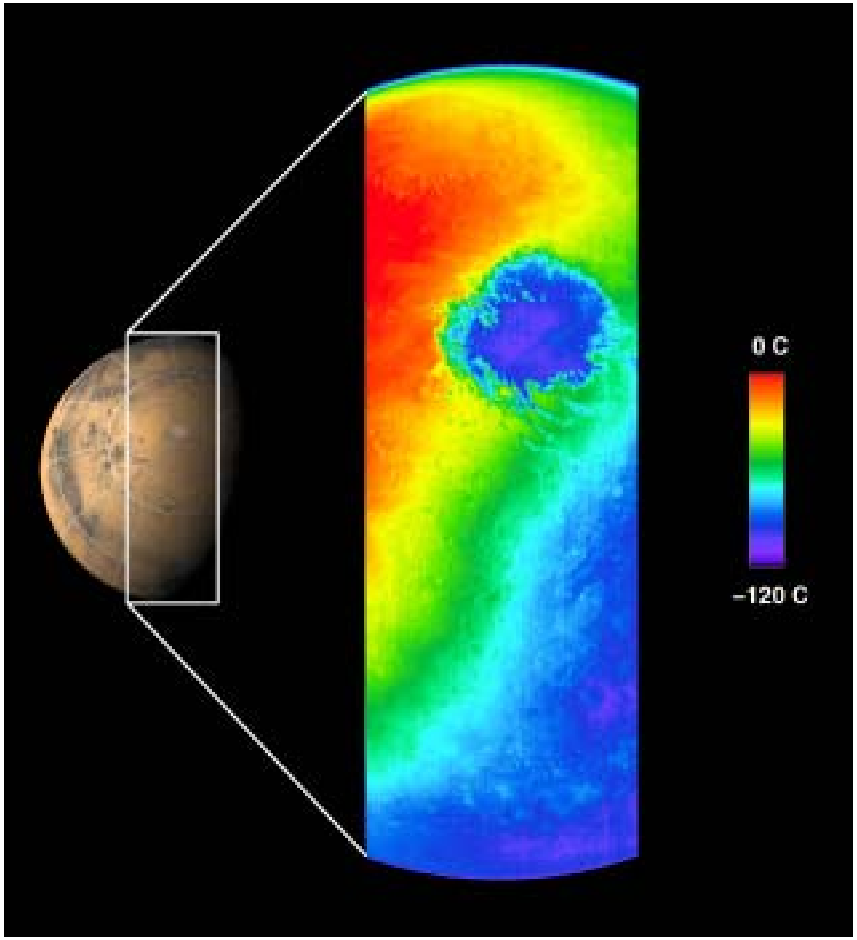
- Black: Measured
- Grey: 5 ppbv CH_4
- Red: 10 ppbv CH_4
- Green: 15 ppbv CH_4
- Blue: 20 ppbv CH_4





Themis (at Mars since Oct. 2001)

- Nadir-pointing thermal emission radiometer
- There is no evidence for “hot spots”.
- But this cannot rule out existing sub-surface magma.



A Mars-Orbiting FTIR Spectrometer

Measurement Capabilities:
• Reduce upper limits on trace gases by 3-4 orders of magnitude
• High vertical resolution (1/3 scale height)
• Atmospheric temperature up to >100 km
• Determine dust composition
• Isotopic fractionation

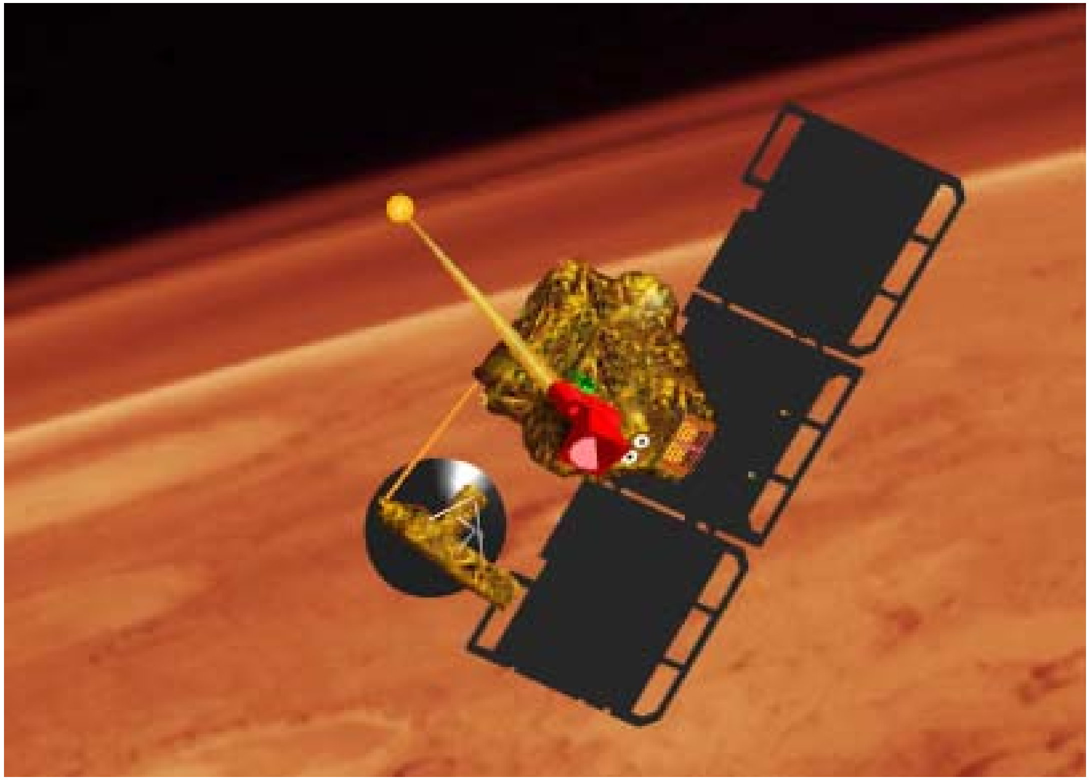
So why hasn’t this already done already?

Challenges:
• 75Gbit/day raw data volume (need on-board processing)
• Accurate pointing stability during occultations (<0.3 mrad)
• Low mass and power (<40 kg; <40 W)
• Cooled detectors (<100K)

MARVEL

In response to the 2001 Mars Scout AO, JPL proposed the Mars Volcanic Emissions and Life (MARVEL) Scout, which featured 3 instruments:

- MATMOS
- SIGNAL
- MICA

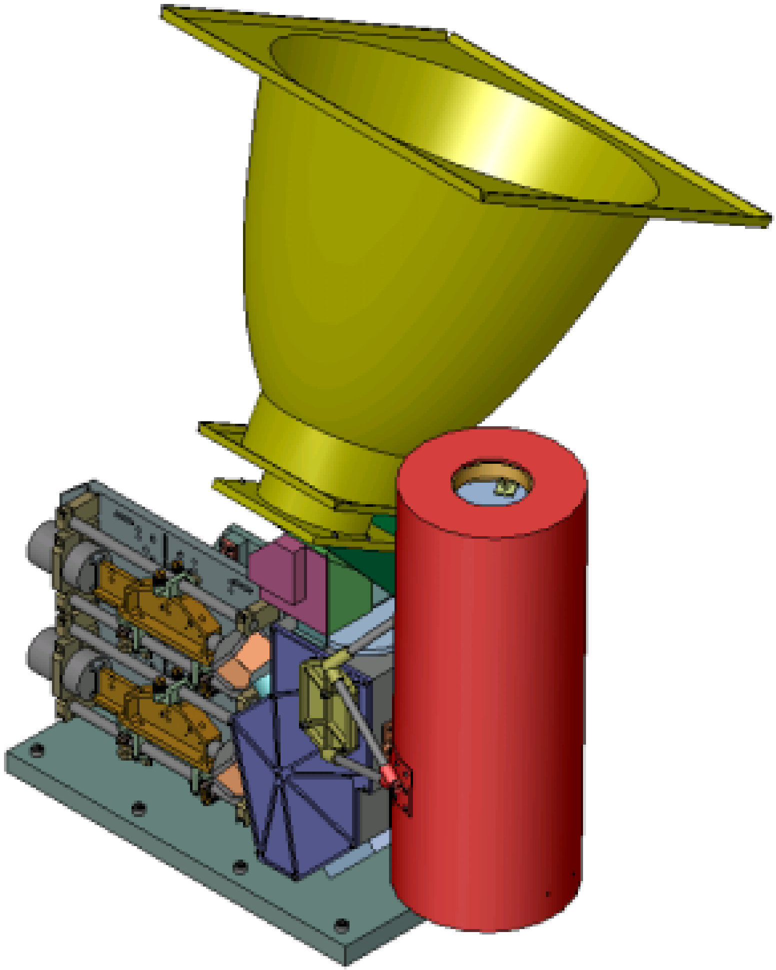


MARVEL was one of 4 proposals chosen for Phase-A study, but was not selected.

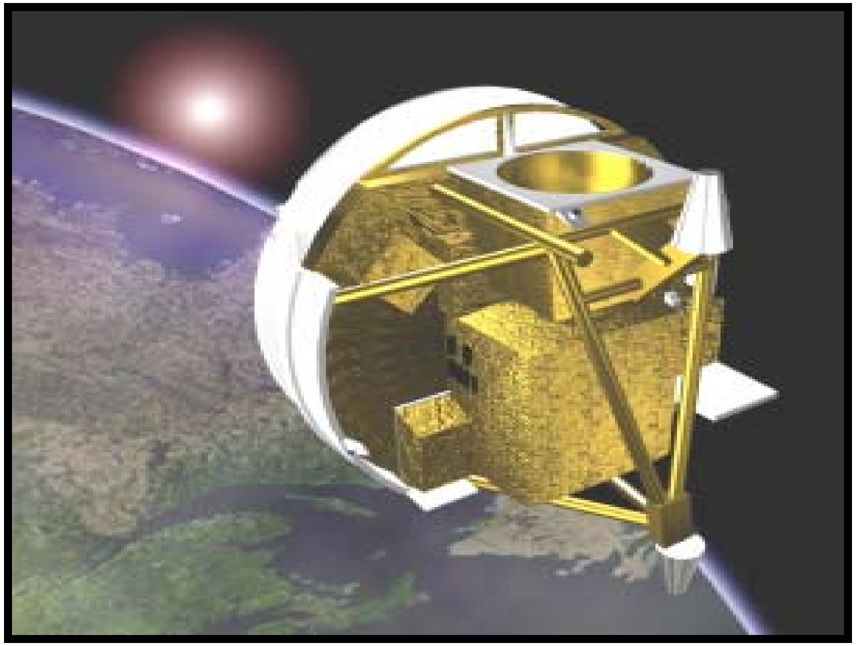
We are optimistic that MARVEL will win the next Mars Scout (2005?).

MATMOS Design Concept

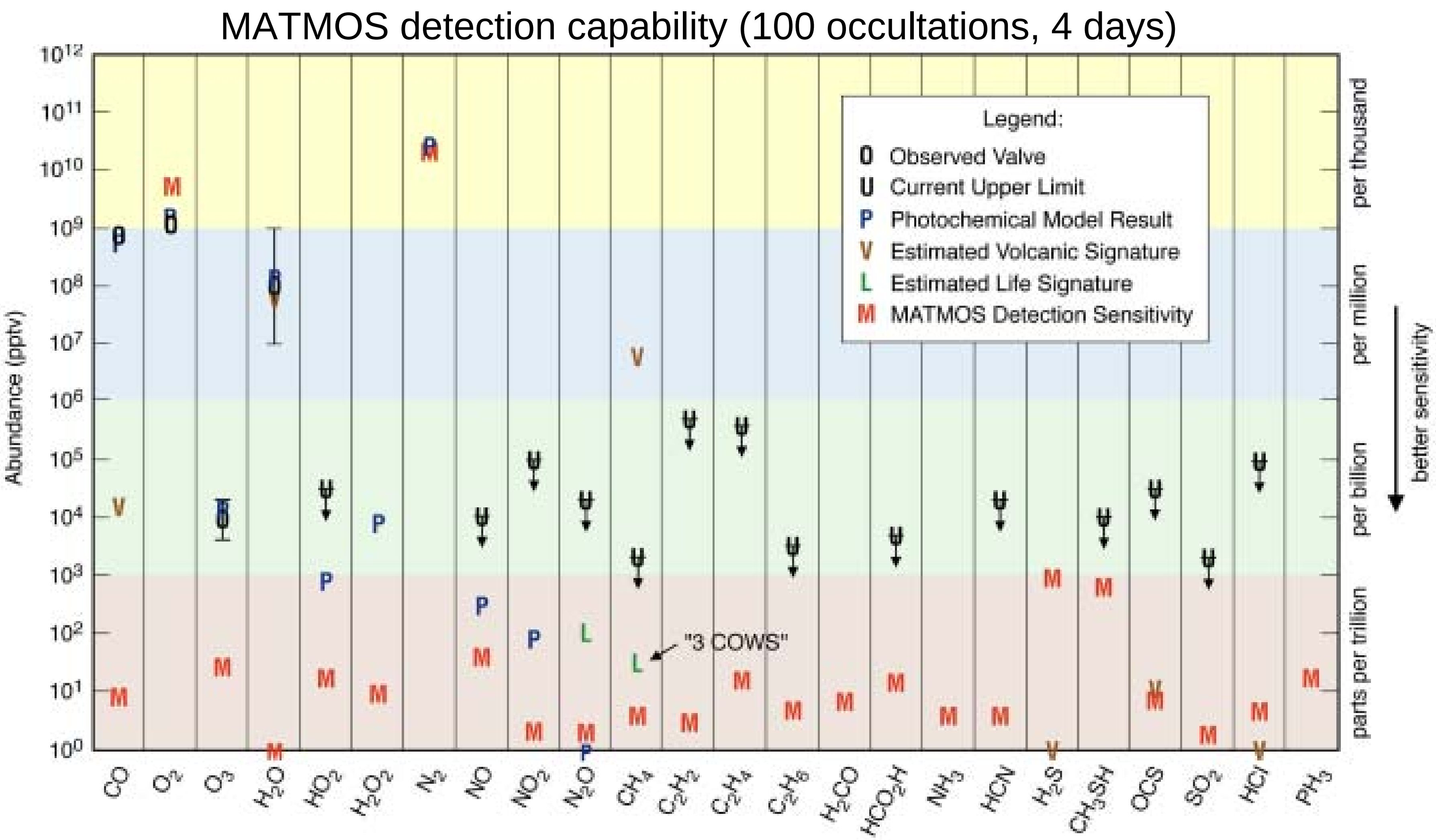
MATMOS INSTRUMENT PARAMETERS		
System	**Property**	**Performance**
Overall Instrument	Mass Power Size	34 kg 71 W (max) 37 W (average) 80 x 56 x 102 cm
Telescope	Magnification Primary Mirror Diameter	5 10 cm
Translation Mechanism	Max Optical Path Diff Scan Repetition Period	± 24 cm 5 seconds
Detectors	Spectral Resolution HgCdTe Bandpass InSb Bandpass Spectrum SNR	0.03 cm^{-1} 850–1850 cm^{-1} 1850–4300 cm^{-1} 400:1
Data Processing	I'gram Sampling Rate Instantaneous Data Rate Raw Data (Interferogram) Processed Data (Spectra)	192 kHz 14 Mbit/s 75 Gbits/day 2.2 Gbits/day
Calibration	Accuracy Frequency	0.2% Each Occultation



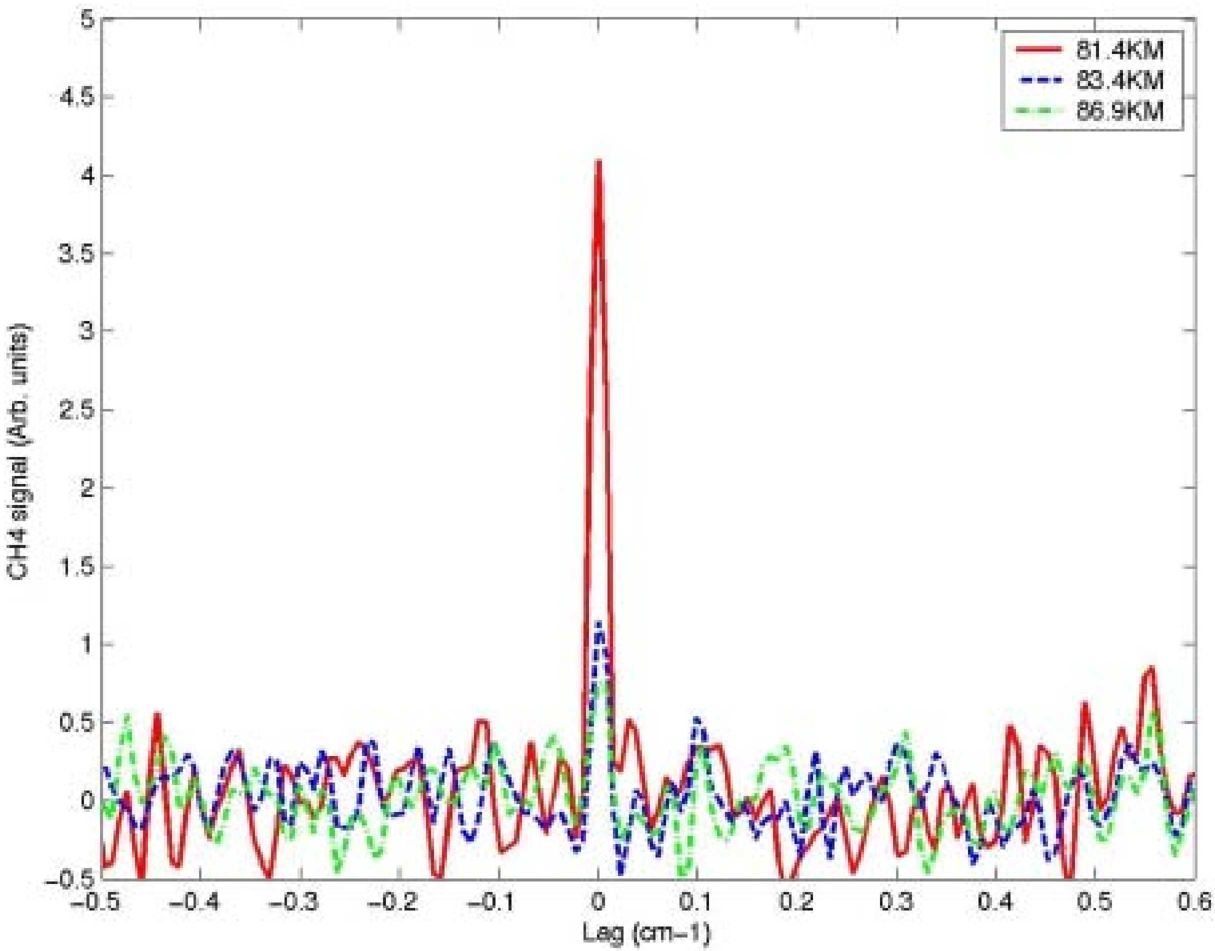
MATMOS Heritage



MATMOS Sensitivity to Trace Gases

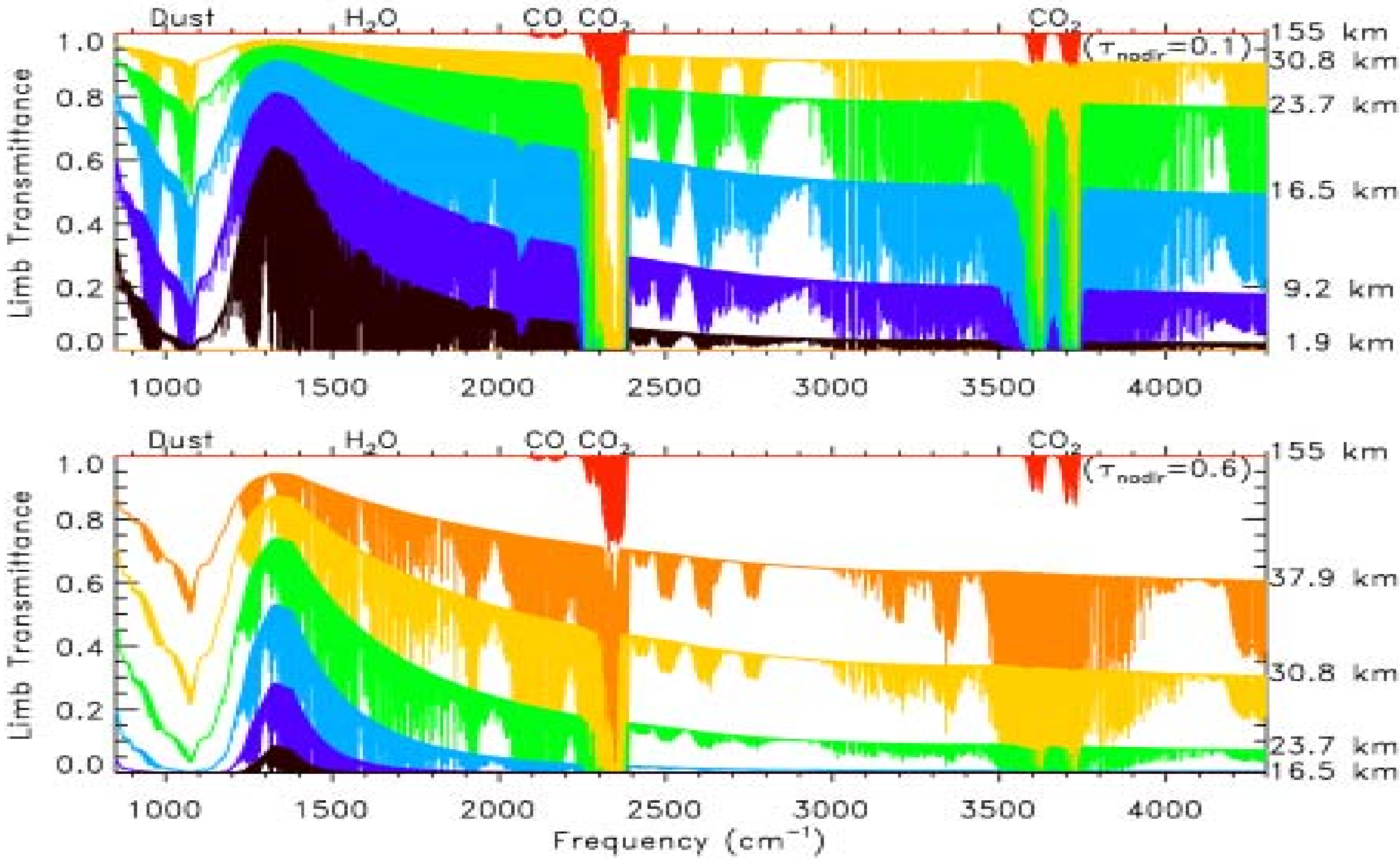


MATMOS CH_4 sensitivity

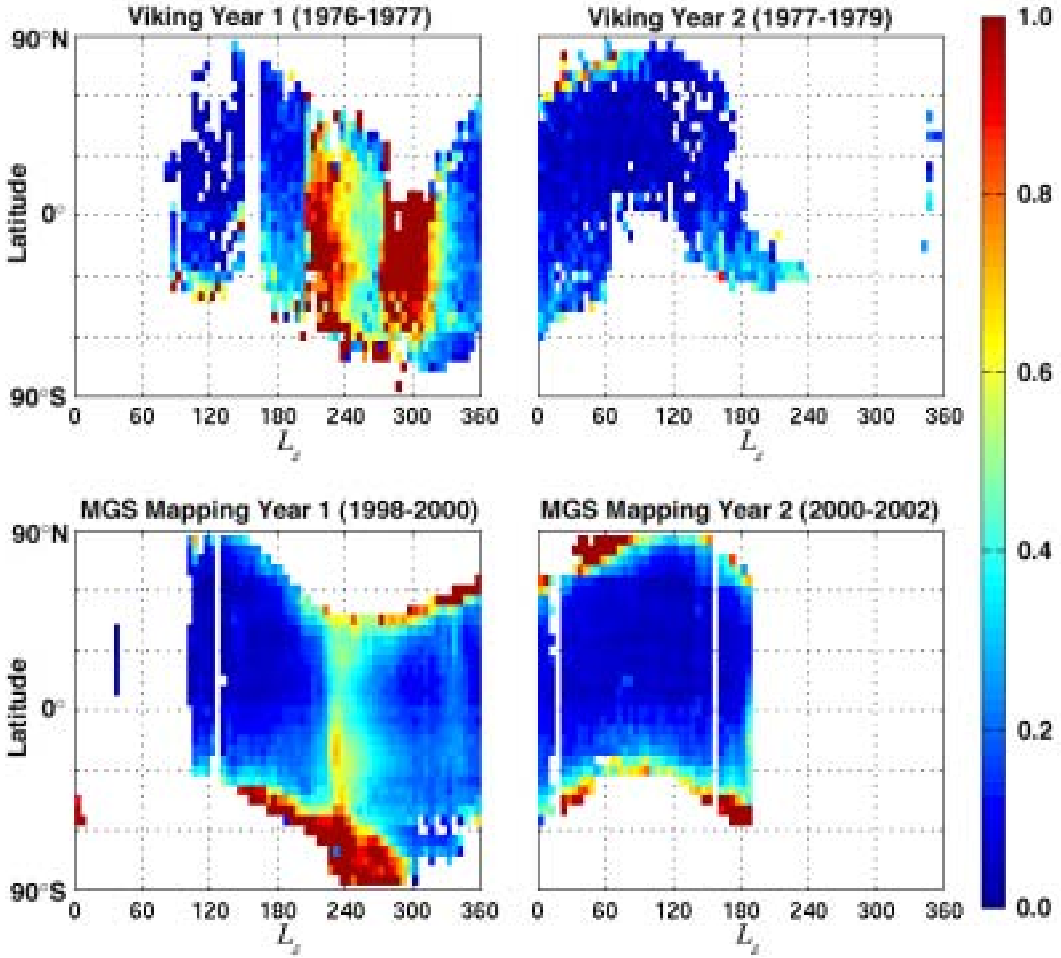


The tiny slant column of CH_4 (1.74x 10^{14} molecules cm^{-2}) at 84 km is easily detected by ATMOS in 1994. Co-averages of the cross-correlation of the 3 µm ν_3 CH_4 band with 25 occultation spectra are shown. The CH_4 column detected at this height is equal to that of 28 pptv of CH_4 in the Martian atmosphere observed at a tangent height of 6 km.

Characterize the chemical and physical properties of the dust



Mars Dust Loading from Viking & MGS



Dust loading is sufficiently light that most occultation observations could reach the surface. Shown here are estimates of the nadir visible optical depth.

Isotopes

- Measurements of the hydrogen, carbon, and oxygen isotopic composition of major and trace gases would yield clues about the modern volatile/surface interactions as well as geological timescale evolution of the Martian atmosphere.
- The isotopic composition of present day Mars materials is poorly known. $^{13}C/^{12}C$, $^{15}N/^{14}N$, and $^{18}O/^{16}O$ of abundant gases are known to no better than ~2%-10%. The H/D ratio is poorly constrained as well (~10%).

MATMOS Isotopic Capability at Mars

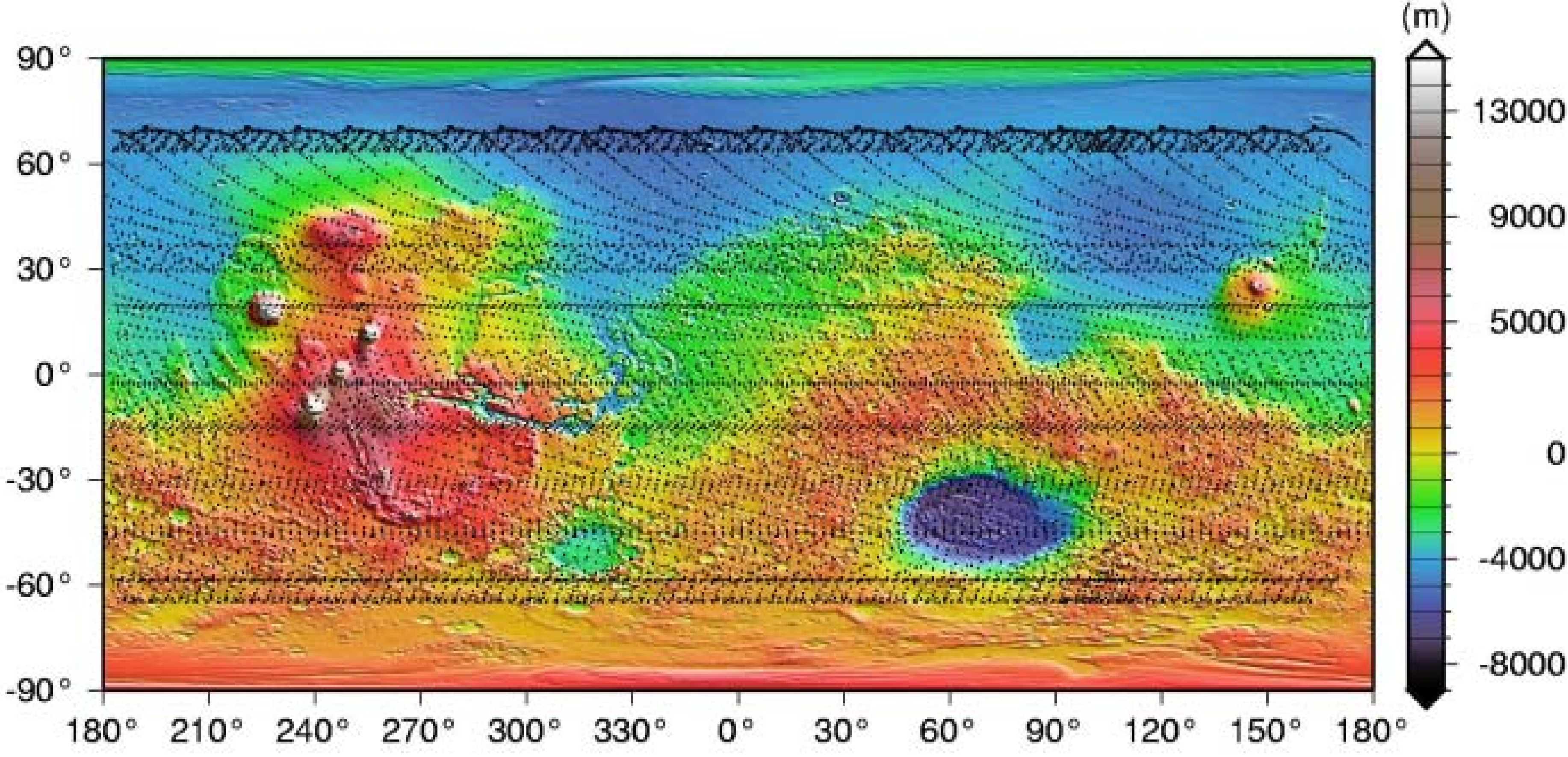
- 100 occultations (~4 days of data)
  - Fabulous Precision (for spectrometeric determination)

Precision of isotope ratio (‰)*

Gas Ratio	τ = 0.1	τ = 0.6
HDO/H_2O	2.5	6.0
$H_2{}^{18}O/H_2O$	1.5	2.5
$H_2{}^{17}O/H_2O$	2.5	3.5
$^{13}CO_2/CO_2$	0.7	0.8
$CO^{18}O/CO_2$	0.7	1.0
$^{13}CO/CO$	2.5	3.5
$C^{18}O/CO$	3.0	3.5

- Accuracy limited by spectroscopic information

MATMOS Spatial Coverage



One Mars year of measurements (17,000 occultations) almost cover the planet

Solar Occultation: Earth vs Mars

Advantages of SO spectrometry at Mars

- Much less cloud
- No refraction (simplifies pointing)
- Lower surface pressure (less broadening)
- Low orbital velocity (reduces instantaneous data rate)
- Sun smaller (less scattering)

Disadvantages:

- Telemetry (5-6 orders of magnitude further away than LEO)
- Power (Sun < half as bright at Mars as at Earth)
- No GPS (self-contained position & pointing)
- Dust (during large storms)
- Radiation Environment (20 kRad TID)

Conclusions

A Mars-orbiting solar occultation FTIR spectrometer would revolutionize our understanding of the Martian atmosphere

- Reduce upper limits of trace gases by 3-4 orders of magnitude

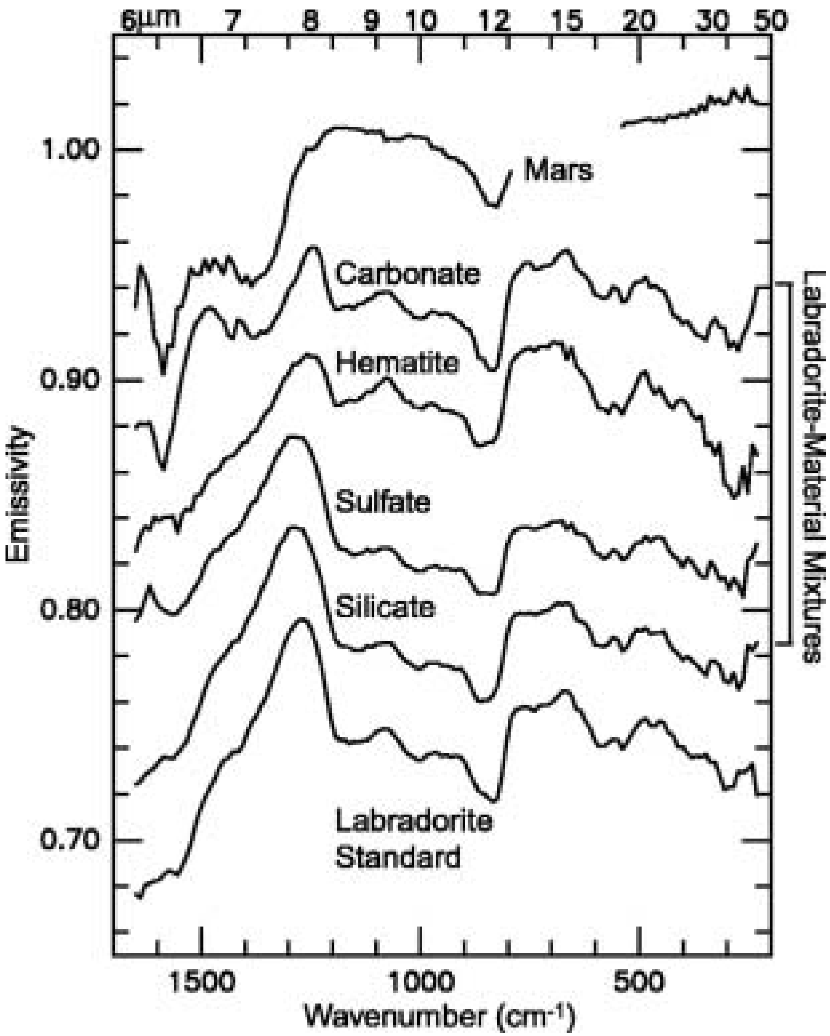
- Accurately determine isotopic fractionations

- Quantify atmospheric inputs from the surface and sub-surface (e.g. volcanism, life).

The technology is now ready for such a mission

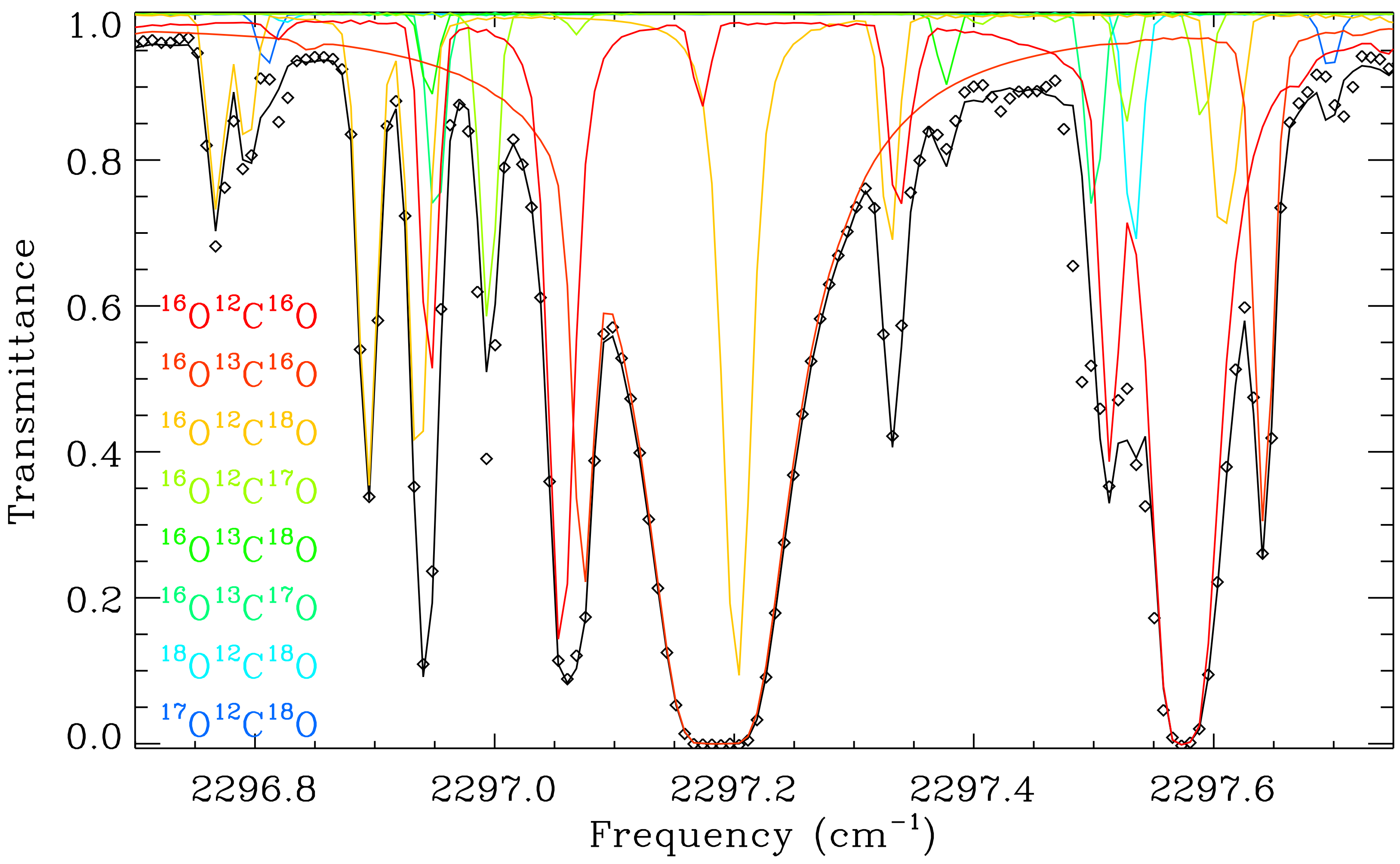
Back-up Material

Carbonates on Mars?

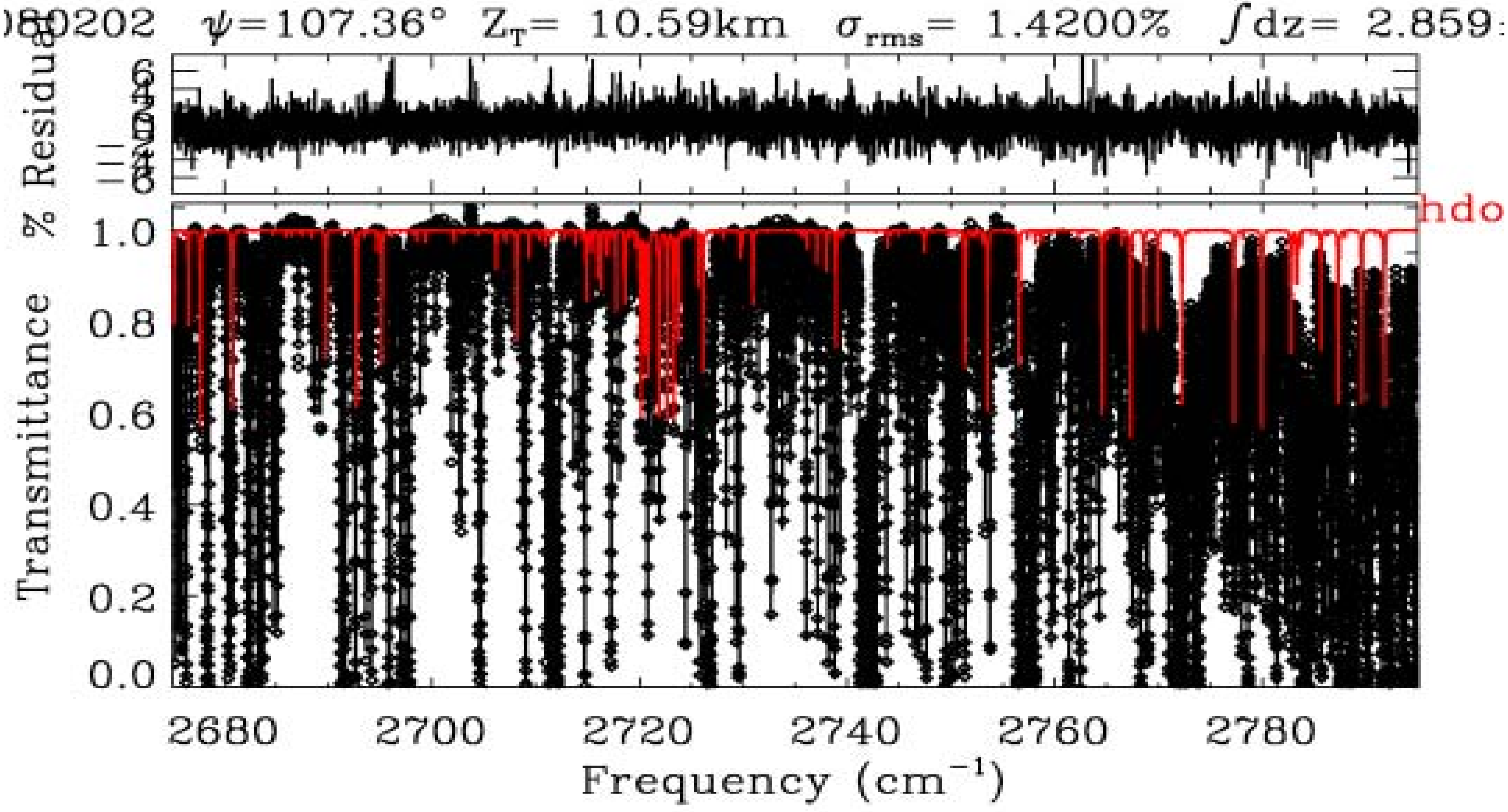


Mars dust, labradorite standard, and labradorite-material mixture spectra (offset). The spectral shape of labradorite is modified considerably with added carbonate at >1300 cm^{-1}, coincident with a fundamental carbonate absorption. The spectral shape outside this spectral region is not appreciably modified because strong silicate absorptions coincide with the other carbonate absorptions. Only the labradorite-carbonate mixture has a notable effect on the spectral shape, except for a peak present in the labradorite-sulfate mixture at 1640 cm^{-1} due to the bound water in gypsum.

"Spectroscopic Identification of Carbonate Minerals in the Martian Dust", Joshua L. Bandfield, Timothy D. Glotch, and Philip R. Christensen *Science* 2003 August 22; 301: 1084-1087.



MkIV spectrum at 38 km tangent height, Fairbanks, Alaska, 1997 shows absorption by 8 CO_2 isotopologues near 2300 cm^{-1}



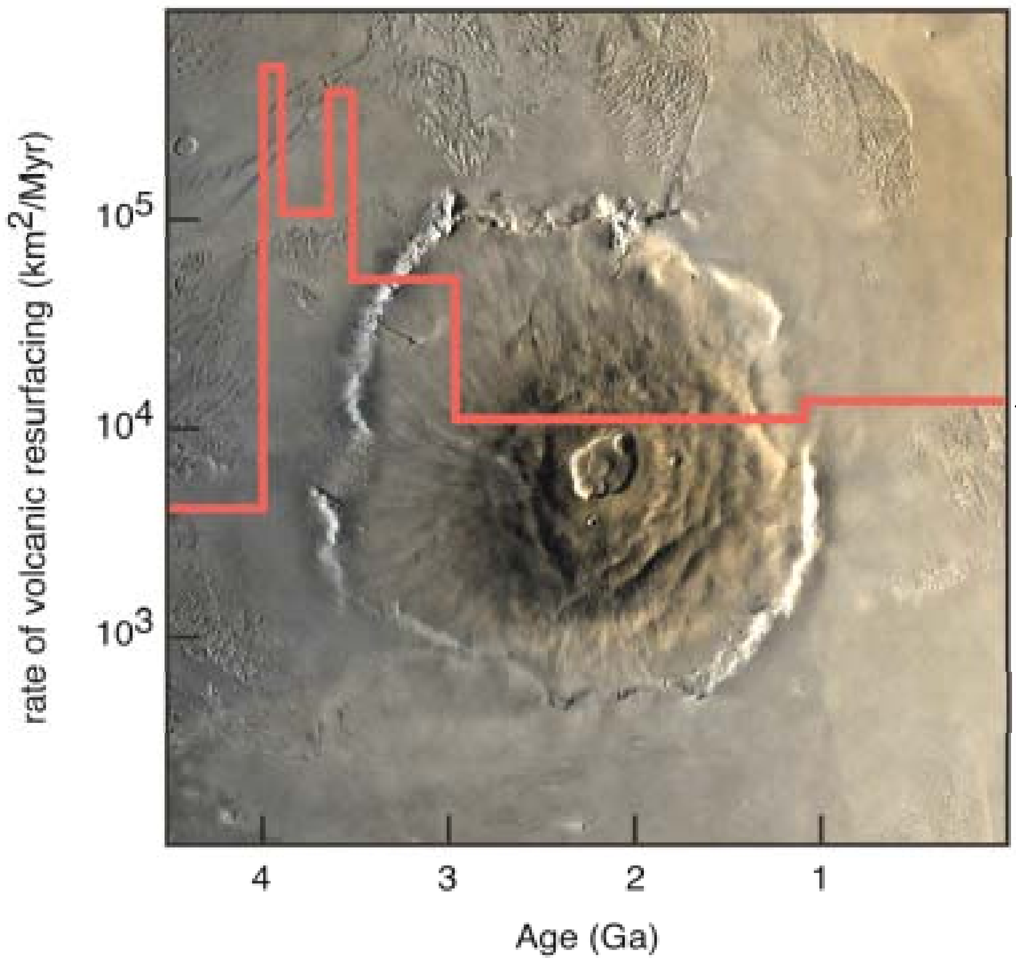
Observations of HDO by ATMOS, 1994, 10 km tangent height

Active Biology

- The Martian Atmosphere looks very close to "dead". The atmosphere is primarily carbon dioxide with small amounts of N_2, O_2.

To date, there has been no systematic search for biomarkers. Ground-based spectra have placed upper limits on several trace gases of possible biological origin (e.g. $CH_4 < 20$ *ppbv)*

Volcanism at Mars



About the Magma production at Hawaii

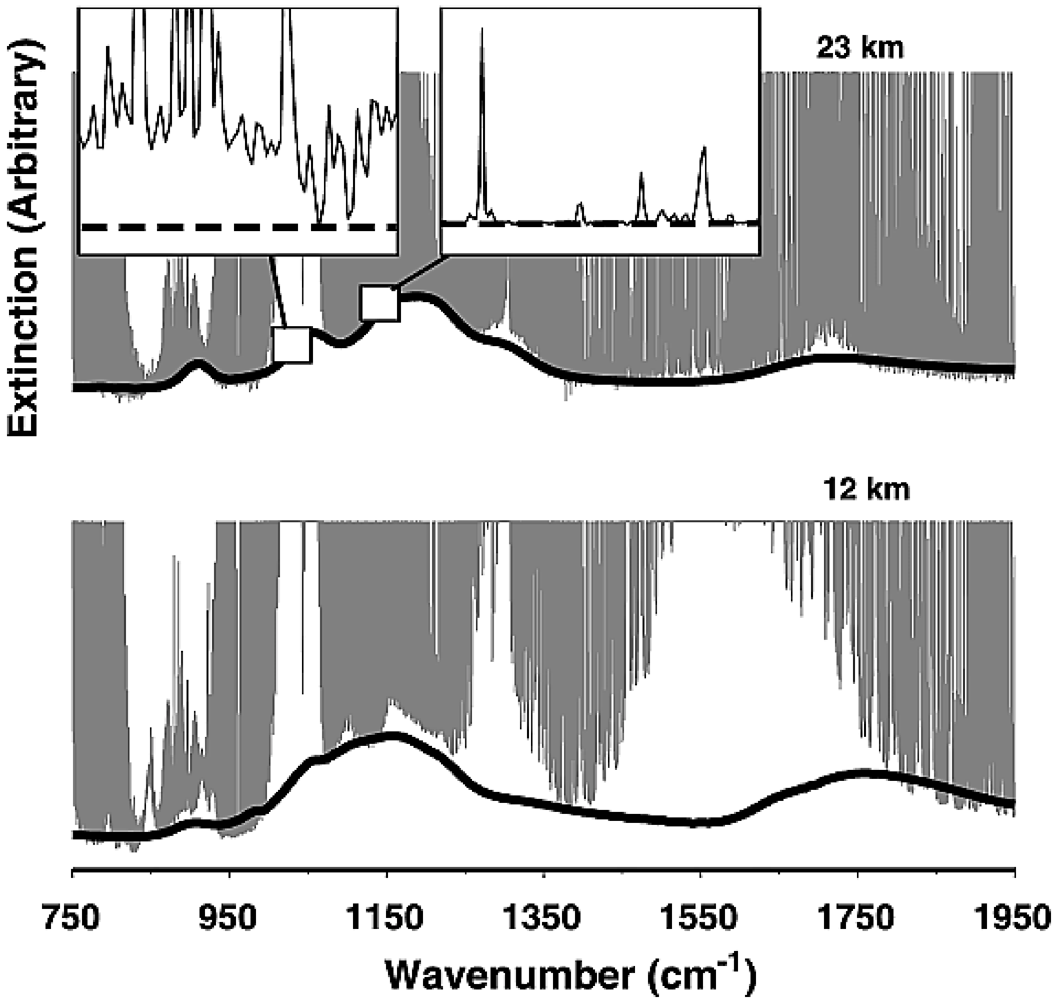
The Martian surface has been continuously modified throughout its history. This is interpreted as evidence for ongoing volcanism.

Volcanic Gases

- As on earth, Martian magmas will contain dissolved volatiles that become supersaturated during emplacement in the shallow crust. After emplacement, these gases will vent to the atmosphere. Hydrothermal interactions also will yield significant volatiles.
- Geochemical studies of Martian meteorites suggest that the parent magmas had similar abundances of carbon, hydrogen, and sulfur to magmas found of Earth.
- The molecular composition of the vented volatiles will be different than those on Earth and will depend on the T,P,H_2O at emplacement. Nevertheless, many of the same reduced and oxidized sulfur-containing gases are expected.

There has been no substantive search for sulfur-containing gases at Mars to date.

Aerosol



ATMOS spectra recorded on March 26 1992 at 29S;188E with filter 9, which covered 600–2500 cm^{-1}, together with best fits for the tangent altitudes of 23 and 12 km.

Grey lines are the ATMOS spectra. Solid black lines are the extracted sulfate aerosol spectra. The insets show bins approximately 0.1 cm^{-1} wide demonstrating a region with strongly overlapped gas absorption lines (left window) and a region with resolved lines and a well-defined baseline (right window).

A. Yu. Zasetsky, J. J. Sloan, R. Escribano, D. Fernandez
B. GEOPHY. RES. LETT., VOL. 29, NO. 22, 2071, 2002

MATMOS Trace Gas Sensitivity

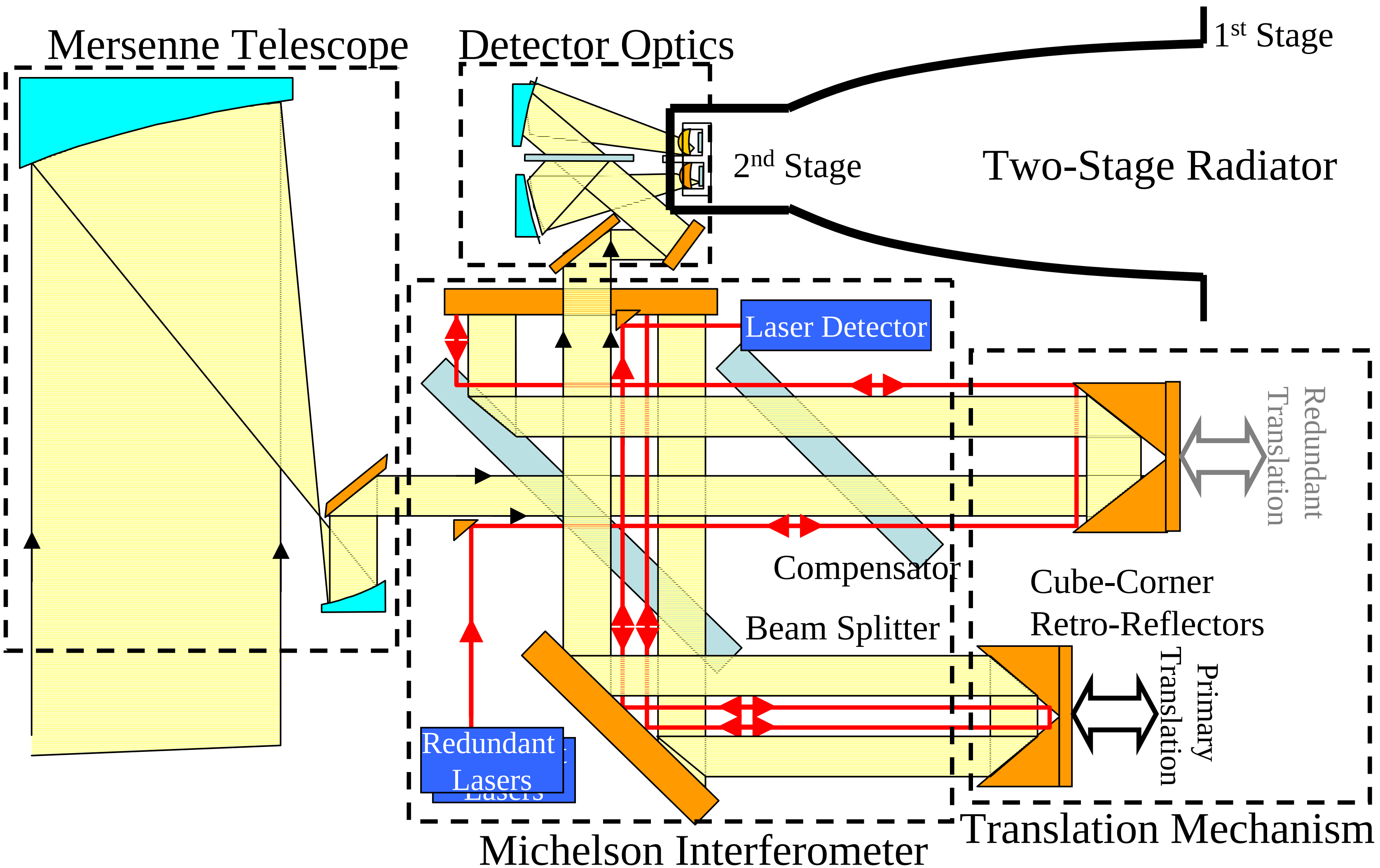
Gas	LOD
CH_4	4 pptv
N_2O	2 pptv
C_2H_6	5 pptv
H_2CO	7 pptv
NH_3	4 pptv
OCS	8 pptv
SO_2	2 pptv
HCl	5 pptv

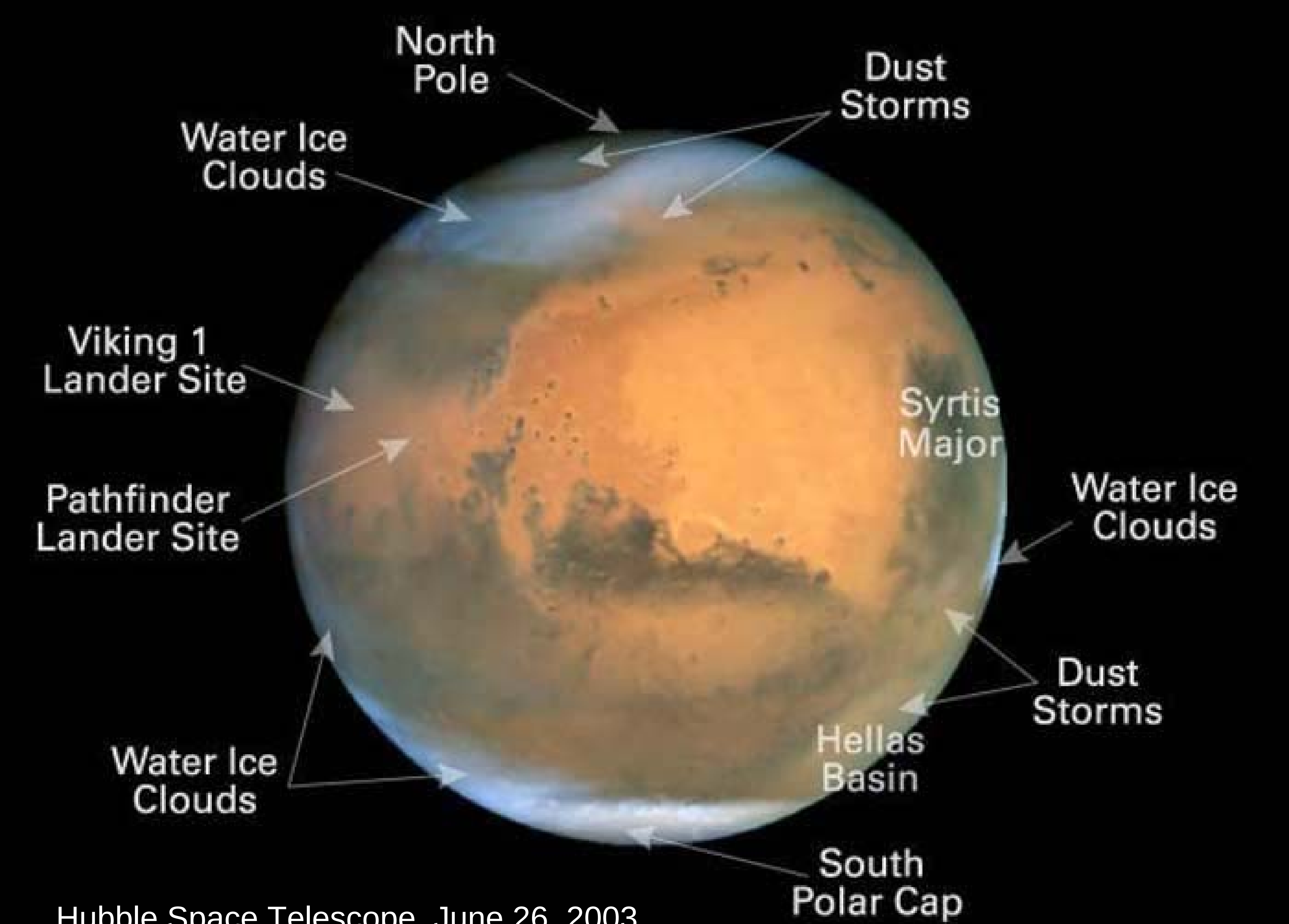
Lifetime of CH_4 is ~300 earth years. To sustain a mixing ratio of 4 pptv, a CH_4 source equal to 1×10^{-10} of terrestrial source is required - about three cows.

Assumptions:

- Continuum S/N = 400
- 0.03 cm^{-1} spectral resolution,
- 850-4500 cm^{-1} ,
- 100 occultations,
- aerosol OD = 0.1 OD

Mars Atmosphere Trace Molecule Occultation Spectrometer (MATMOS)





Hubble Space Telescope, June 26, 2003.