Methane in Mars' Atmosphere: Evidence for Life or Uncertain Detections?

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Scientific category: SOLAR SYSTEM
Instruments: EXES
Hours of observation: 10

Abstract

Methane has recently been reported in the atmosphere of Mars. Its presence, if it can be confirmed, may have implications for the past or current presence of life on Mars. However, ground-based observations are severely hampered by telluric interference, whereas space-based observations have been made with spectral resolution ill-suited for observations of gasses. EXES on SOFIA will have a spectral resolution comparable to methane line widths and will have a sufficiently small column of methane overhead to make observations and mapping of Martian methane straightforward.

Observing Summary:

Target	RA	Dec	F_{Jy}	Configuration/mode	Hours
MARS		ecliptic	240K BB	$R=10^5$ STEP MAP	8
MOON		ecliptic	270K BB	$R=10^5$ NOD	2
				Grand total hours	10

Scientific Objectives

Methane, CH_4, is abundant in the atmospheres of the giant planets and is thought to have been abundant in the early atmosphere of the Earth. In low-temperature hydrogen-rich environments it is the dominant carbon-containing molecule. It is much less abundant in the present-day atmospheres of the terrestrial planets where most of the carbon is in CO_2. Most of the CH_4 in the Earth's atmosphere is biogenic, either from current life or from fossil deposits of past life.

Detections of methane have recently been reported in Mars' atmosphere through high-resolution ground-based spectroscopy (Krasnopolsky et al. 2004, see Fig 1; Mumma et al. 2004), and low-resolution spectroscopy from Mars orbit (Formisano et al. 2004). The ground-based spectra are severely affected by telluric features. The orbiter doesn't have this problem, but is relatively insensitive to narrow absorption lines. None of the published detections is of very high statistical significance. Krasnopolsky et al (2004) reports a CH_4 mixing ratio of 10±3 ppb (parts per billion) using a single aperture covering 40% of the martian disk; they argue CH_4 should be well-mixed in the martian atmosphere and suggest no spatial variation should be expected unless *in situ* observations are made. Formisano et al. (2004) also measured a global average mixing ratio of 10±5 ppb, but measurements of different regions ranged from 0 to 30 ppb.

The origin of CH_4 in Mars' atmosphere in the quantities reported is difficult to understand. No mechanism for its formation in the atmosphere has been suggested, and its lifetime prior to photochemical destruction has been estimated to be ∼340 years (Krasnopolsky et al. 2004). CO_2 can react with high temperature water to form CH_4, but this reaction produces very little CH_4 in the interior of the Earth, and probably produces even less CH_4 in Mars. Comets and meteorites may bring CH_4 to Mars, but estimates of the average delivery rate are well below that required to explain the observed abundance. Perhaps the most likely abiogenic origin of CH_4 in Mars' atmosphere is a recent cometary impact. The probability of a sufficiently recent impact is small but not zero.

The difficulty of explaining the reports of CH_4 in Mars' atmosphere with abiogenic sources has led to consideration of the possibility of methanogenic bacteria or other other biogenic sources of CH_4. The presence of life on Mars would profoundly impact our understanding of our place in the Universe. But before such a possibility should be taken seriously, the observations of CH_4 must be confirmed with improved sensitivity.

SOFIA Uniqueness/Relationship to Other Facilities

Methane in the Earth's atmosphere causes strong pressure-broadened absorption lines for all lines which might be detected in Mars' spectrum. ¿From ground-based observatories these pressure-broadened lines are nearly opaque out to the maximum Doppler frequency offset caused by the motions of the planets. Twenty percent of the telluric CH_4 remains above the altitude of SOFIA, but because pressure-broadened lines are 80% narrower at that altitude, Mars' Doppler shift will bring its CH_4 lines out of the the saturated line cores. EXES will be able to observe the strong ν_2 and ν_4 bands of CH_4 near 7.6μm wavelength with a spectral

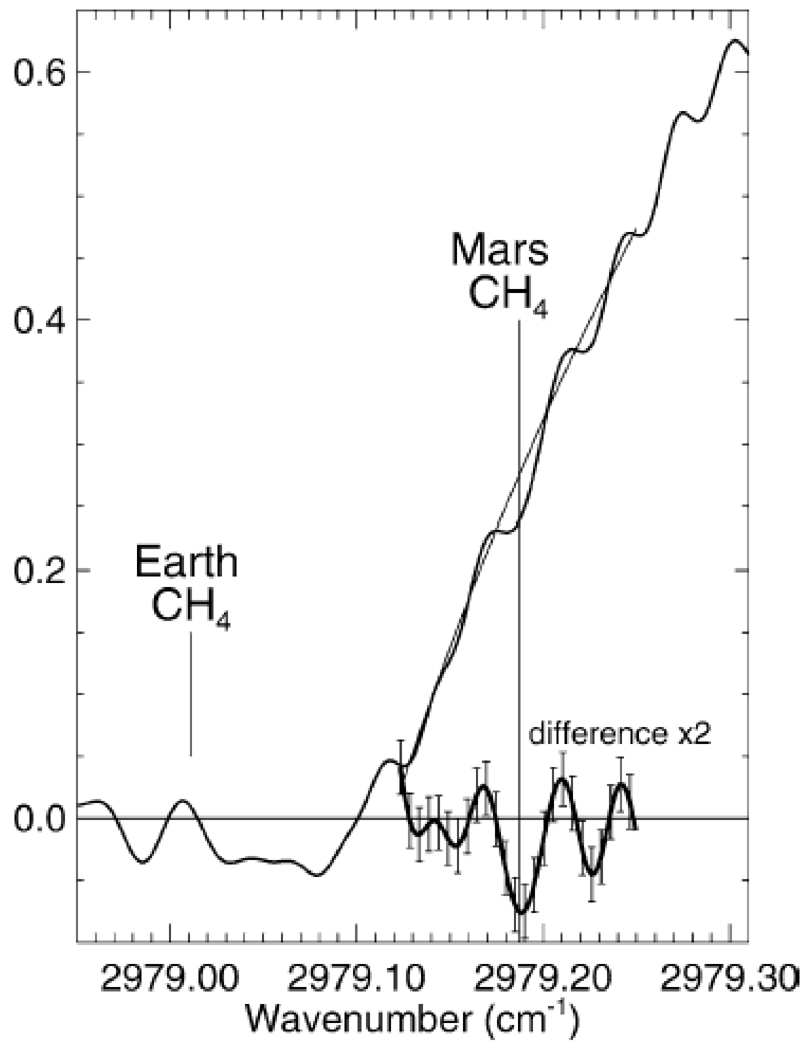
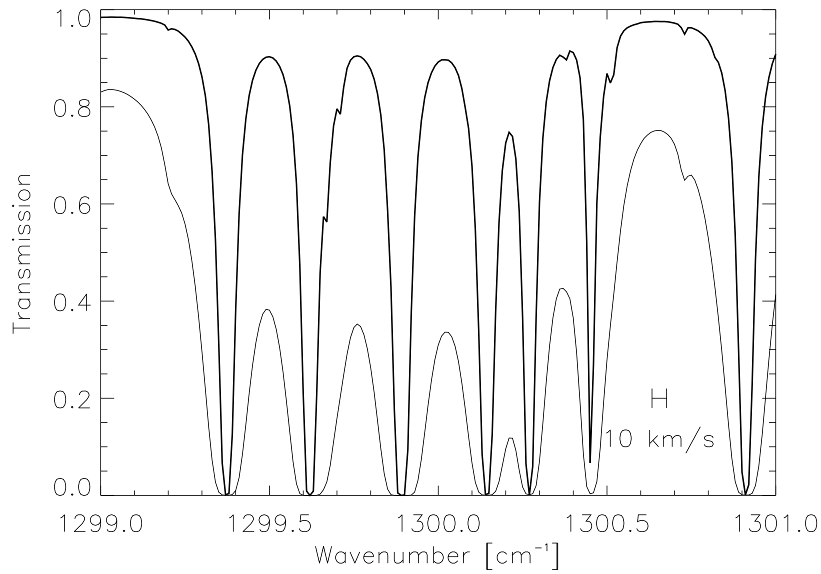


Figure 1: Blue wing of strongest methane telluric line in the Krasnopolsky et al (2004) detection of methane. The expected positions of the line center and the Doppler-shifted martian line (−17.76 km/s) are shown. 75 points near the martian line are fitted by a cubic parabola (thin line). Difference 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. (Figure 3 and caption from Krasnopolsky et al. 2004)

Figure 2: A comparison of atmospheric transmission from Mauna Kea (lower line) and SOFIA (upper line).



resolution of $\sim$3 km s^{-1}, sufficient to separate the martian and telluric absorption lines (Fig 2).

Other observatories are unlikely to solve this issue. The atmospheric pressure on Mars is so low that EXES will not resolve the lines. Infrared space observatories, such as Spitzer and JWST, have much lower spectral resolution, so that S/N >> 1000 will be required to detect the lines. Ground-based observations in the mid-IR are prevented by the telluric CH_4. Because CH_4 is a symmetric molecule, it has no rotational transitions and so is unobservable at mm wavelengths.

Observing Strategy

A test of the reported detection of CH_4 could be made in a few minutes on SOFIA. For the reported 10 ppb CH_4 abundance, typical lines in the 7.6μm CH_4 bands will have equivalent widths $\sim 10^{-4}$ cm^{-1}, and depths $\sim$1% at EXES' resolution. The continuum signal-to-noise per pixel for a 240 K blackbody filling the slit will be roughly 100 for a 10 second integration. A four minute integration would give a 5σ line detection. We will be able to bin the pixels 3 by 2 and still Nyquist sample the seeing disk and the resolving power, giving an $\sim 10\sigma$ detection of the line in 3 minutes per map position. This will enable us to look for variations in the CH_4 abundance at roughly a dozen separate positions per hemisphere.

Scanning an entire hemisphere to a SNR=1000 would take roughly 4 hours. At a time when the Doppler shift of Mars is roughly 10 km/s, as required to separate martian atmospheric lines from telluric ones, the martian disk will be roughly 10 arcseconds in diameter. The EXES slit will be roughly 1.5 arcseconds wide and 5 arcseconds long. It is possible a longer slit could be used at the cost of more limited wavelength coverage. We will spend on order 3 minutes per slit position and nod Mars completely off the slit for a total time of 6 minutes for a single slit position. We will step the slit by $1''$ across the disk of Mars and will have to make two maps to cover the full hemisphere. The total observing time for a single map would then be 6 minutes $\times$ 10 positions or 1 hour. There will be additional overhead for telescope settling time after a nod, wavelength calibrations, observations of a blackbody, target acquisition and initial positioning of the slit. Since many of these factors are poorly determined at this time, we simply assume the overhead is an additional factor of 2. Therefore, the total elapsed time for a single map across Mars will take 2 hours. Each map will likely require its own flight leg and mapping the full hemisphere will take 2 flights in a series. Since a Mars Sol is about 40 minutes longer than a terrestrial day, mapping the entire planet could be done by observing again 20 days later.

Before or after the Mars observations, it will be necessary to record very high signal-to-noise observations of the Moon. These observations will serve as a telluric calibrator, will be done by nodding the Moon fully off the slit, and will take roughly 30 minutes.

Special Requirements

We need to be able to stay on Mars and the Moon.

Minimum Spectral Resolution:	100,000 at 6 – 8 μm
Maximum water:	medium
Maximum tracking blur:	1000 mas
Minimum tracking rate:	20 mas/sec
RMS pointing jitter:	2.0 as
Minimum science data volume:	10 GB/day or observation
Minimum precision/pixel dynamic range:	1000

Precursor/Supporting Observations

No supporting observations