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Mid-Infared Laser Heterodyne Instruement (MILaHI): for sensitive search of trace gases on Mars

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Abstract

We will begin to perform observation with Mid-Infrared Laser Heterodyne Instrument (MILaHI) onboard our dedicated telescope at the top of Mt. Haleakala from August 2014. The ultra-high spectral resolution of MILaHI can fully resolve the narrow features of trace gases in the Martian atmosphere.

1. Introduction

Although trace gases are present in small concentrations in the atmosphere of Mars, they have important role in the dynamics, photochemistry, geological and biological activity, and water cycle on Mars. A number of trace gases exhibit rotational-vibration bands in the mid-infrared regime. Therefore, mid-IR spectroscopy is one of the powerful tools to study trace gases. Since the line widths are very narrow due to the low pressure of the Martian atmosphere, high spectral resolution ($R>10^6$) is significant indispensable to fully resolve their features. However, the present state of world instruments to direct detection methods like grating spectrometers or fourier transform spectroscopy still do not achieve an adequate high-spectral resolution (e.g., IRTF/TEXES: $R\sim10^5$). In mid-infrared wavelength region, the highest spectral resolution is provided by the infrared heterodyne technique [1]. It has been applied to study of planetary atmosphere to date and has reported innovative results (e.g., [2]).

2. Instrument and Characteristics

We have developed a new infrared heterodyne instrument, called Mid-Infrared Laser Heterodyne Instrument (MILaHI) in Tohoku University, Japan. We will begin to perform unique observations with MILaHI onboard our dedicated telescope at the top of Mt. Haleakala from August 2014. The scientific targets of MILaHI are not only trace gases on Mars but also molecular in the atmospheres of solar planets. The nature of the atmospheric activity in various time-scale will be investigated by continuous monitoring with our dedicated telescope. Remarkable advantages of this instrument are as follows: (i) ultrahigh spectral resolution up to 10^7 with a bandwidth of 1 GHz, (ii) compactness within 600mm x 600mm including the calibrators, (iii) excellent system noise temperature less than 2700 K at 9.6 micron wavelength. In order to provide wider wavelength range, a room-temperature type quantum cascade laser (QCL) was applied. Its operating spectral range achieved to be 5 cm^{-1}. As the backend spectrometer, a compact digital FFT spectrometer was first applied for our system in order to obtain (a) a high frequency resolution, (b) stability and flexibility, and (c) a wide dynamic range.

3. Detectability of trace gases in the Martian atmosphere

The operating wavelength range of the instrument is determined by the tuning range of QCL. At the moment, 3 types of QCLs operating at 970, 1045, and 1295 cm^{-1} are mounted in MILaHI. These wavelengths can be addressed to detect the lines of CH_4, H_2O_2, HDO, CO_2 isotopes, and O_3 in the Martin atmosphere. Figure 1 shows the synthetic spectra with the expected spectral resolution of MILaHI ($R=10^6$) using the QCL working at 1295 cm^{-1}. Based on the simulation, we estimated the integration time for detection of these gases. We assumed the system noise temperature was 5000 K from the last test-observation of Moon. With the condition, the required integration-times to detect 10 ppb of CH_4, 10 ppb of H_2O_2, and 93 ppb of HDO (which corresponds to 1 wrt VSMOW at 150 ppm of H_2O) with 3-sigma confidence are ~ 18 hours, 6 hours, and 1.5 hours, respectively. The required integration-times are longer than direct detection method like grating spectrometer, however, MILaHI can fully resolve the lines of CH_4, H_2O_2, and HDO on Mars, as shown in Figure 1. MILaHI will become a unique facility for continuous monitoring of trace gases in the Martian atmosphere with ultra high-spectral resolution.

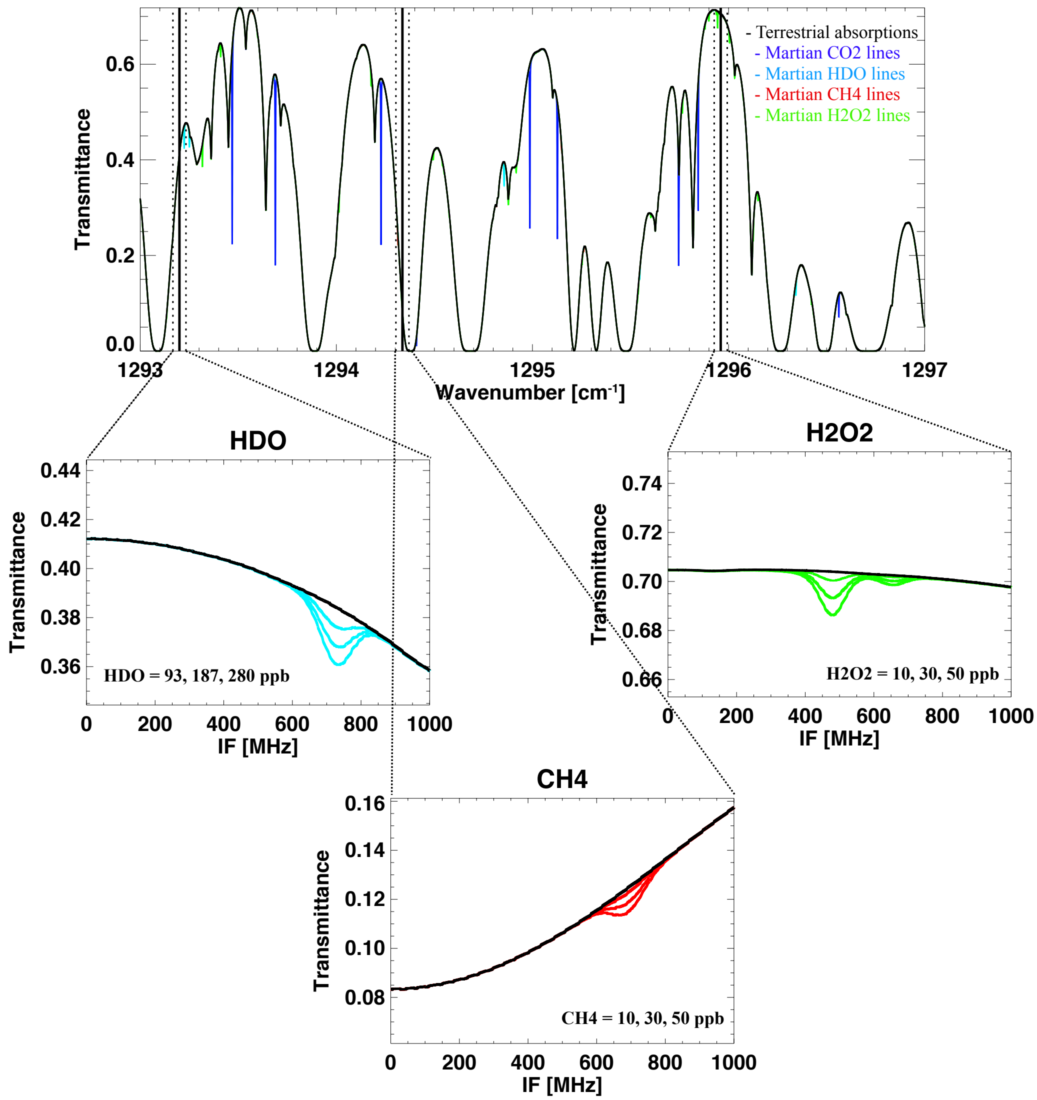

Figure 1: Synthetic spectra with the expected spectral resolution of MILaHI ($R=10^6$) in the spectral range between 1293 and 1297 cm^{-1}. The doppler-shift between Mars and Earth is assumed to be 15 km/s. The black curves show the transmittance due to the terrestrial atmosphere at 3 km of altitude. The vertical black lines shown in the top figure represent the assumed wavenumber of QCL operation (3 cases: 1294.337 cm^{-1} for CH_4, 1293.20 cm^{-1} for HDO, and 1295.96 cm^{-1} for H_2O_2). The color lines represent the synthetic spectra of CO_2, HDO, CH_4, and H_2O_2 with various mixing ratio (Blue: CO_2=0.953, Light blue: HDO=93, 187, 280 ppb (which corresponds to 1, 3, 5 wrt VSMOW at 150 ppm of H_2O, Red: CH_4=10, 30, 50 ppb, Green: H_2O_2 = 10, 30, 50 ppb). The dust and water ice at the Martian atmosphere are not taken into account in this simulation.

References

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