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Mid-infrared Heterodyne Spectroscopy Dedicated to Observation of Planet at Haleakala, Hawaii

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Abstract

The infrared heterodyne spectroscopy is an unique powerful tool for atmospheric studies with ultra high-spectral resolution, high sensitivity, and downsizing. Ultra high-spectral resolution observations enable us not only the definite detection of the tiny minor constituents, but also to obtain the vertical profiles of the molecules using retrieval method and wind velocity using Doppler shift of the emissions. In this study, we introduce the current status and its performance evaluation of the compact heterodyne spectroscopy for the dedicated telescope in Mt. Haleakala, Hawaii.

1. Introduction

Many molecules in planetary atmospheres show transitions in the mid infrared regime. High-resolution spectroscopy in this regime is significantly indispensable to detect minor constituents precisely, and to derive the dynamics (wind/temperature) with high accuracy in the planetary atmosphere in distinction from the strong terrestrial absorptions. 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., $R=10^5$). Mid-infrared heterodyne spectroscopy has proven to be a powerful tool for planetary and astrophysical studies. To achieve highest spectral resolution (10^{7-8}) and sensitivity as well as compact instrumentation heterodyne systems are significantly advantageous over direct-detection methods. Actually, infrared heterodyne techniques developed by NASA/GSFC and University of Cologne are world's leading producers of very unique achievements to obtain very high precise measurements of planetary atmosphere [1,2]. Our group in Tohoku University, Japan, has also developed own heterodyne system to observe the minor constituents in the terrestrial atmosphere from 1980s [3]. Recently, we applied this heterodyne technique for planetary observation using CO_2 gas laser and the quantum cascade (QC) laser for use as local oscillator (LO) in a heterodyne receiver. Our heterodyne spectroscopy is specially designed for the dedicated telescope, PLANETS (2012-) at the Mt. Haleakala, Maui, in Hawaii with the international collaboration. Since a telescope dedicated to for observation of planets does not yet exist, it is expected the telescope and mid-infrared heterodyne spectroscopy will become a unique facility for continuous monitoring of planetary atmosphere with ultra high-spectral resolution.

2. Instrumentation

The heterodyne spectroscopy is a receiver in the mid infrared wavelength range between 9 and 11 um. The operating wavelength range is determined by the tuning range of the LO. Currently, the distributed feedback (DFB) QC lasers at 9.6 and 10.3 um and the Fabry-Perot (FP) QC laser at 8.0 um with room-temperature control manufactured by HAMAMATSU photonics, and CO_2 gas laser at 10.3 um can be operated. Previous studies commonly used a liquid-nitrogen cooling for driving lasers, and the tuning range of QC laser was very limited (1 cm^{-1}). Using temperature control (-30 degree to 30 degree), a room-temperature type QC laser provides very wide tuneability (> 5 cm^{-1}) (see Figure 1). Furthermore, using FP QC laser combined with an external cavity provides wider tuneability (20 cm^{-1}), greatly expanding the accessible wavelength range and multi-detections.

The frequency stability of the system is determined in order to qualify the instrument for high-resolution observations. This is especially important for observations of weak signals requiring long integration times. Therefore, it has been evaluated by heterodyne measurements between QC laser and CO_2 gas laser. Data were taken every 0.1 s over 1 min. for each driving current, and the temperature control was performed by 0.01 K accuracy. The observed variation of the wavelength is distributed in the range of 100 MH, corresponding to 10^5 resolution without any stabilizer or feedback. With stabilizer (e.g., Diplexer), the spectral resolution is expected to be better than 10^7. As a photo-mixer detector, we use a Mercury-Cadmium-Telluride photo diode manufactured by Raytheon vision systems. Combing detection of LO and the signal, the mixer generates an IF signal with a bandwidth of up to 3 GHz in double side-band. The real-time analysis of the IF signal is provided by a digital FFTS (DFT) available from Acqiris. It receives 8-bit samples from the analog-to-digital converters (ADC) at a continuous sample rate of 2 GHz, and 16384 channels determine the frequency resolution for DFT spectrometer to be 61 kHz.

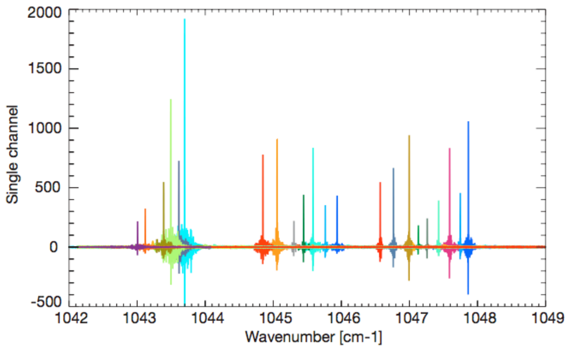

Figure 1: Emission spectra of the DFB QC laser in a peltier cooling head in the range between -20 degree and 20 degree.

Sensitivity of the instrument is an important parameter, which determines the detection limit of the instrument. In Figure 2, we show the system noise temperature using CO_2 laser. At 10.3 um wavelength a mean Tsys of 9500 K is achieved. A system noise temperature of 9500 K leads to a minimal detectable brightness temperature difference of 190 mK within 10 min. at the bandwidth of 1.5 MHz, corresponding to a minimum flux difference of $\Delta F_{1/\lambda} = 1.52 ergs/scm^2cm^{-1}sr$ for extended sources.

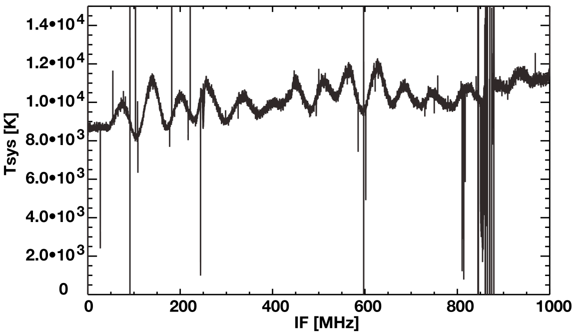

Figure 2: Instrument performance at 10.3 um. The system noise temperature is shown. The fluctuation with IF frequency are due to impedance mismatch and standing waves in the IF processing electronics.

6. Summary and Conclusions

We present the current status and its performance of the heterodyne instrument. Many interesting scientific problems have been targeted and more will be addressed in the future with the technological advances of the instrumentation described here. By continuous monitoring using the ultra high-spectral resolution observations, the understanding the evolution of the planetary atmosphere is expected to be significantly accelerated.

Acknowledgements

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