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Scientific capabilities and measurement sensitivities of the IR heterodyne spectroscopy

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Many molecules of atmospheric and astronomical interest exhibit rotational-vibrational spectra in the middle infrared (IR) regime. Fully resolved molecular features with high spectral resolution are possible retrieval of many physical parameters, such as density, velocity, pressure, excitation condition, temperature, and the vertical information from single line profile. In the mid-infrared wavelength region, the highest spectral resolution is provided by the IR heterodyne technique (Kostuik and Mumma, 1983). It is for the applications to astronomy and planetary atmospheric science in 7-13 micron wavelength at the spectral resolution of up to 1E7-8 (corresponds to 1-10m/s) with a very high sensitivity. Notable successes on Venus, Mars, Jupiter, Titan and Earth were given by NASA Goddard Space Flight Center, University of Cologne, and Tohoku University (Fukunishi et al. 1990; Taguchi et al., 1990; Goldstein et al., 1991; Kostuik, 1996; Kostuik et al., 2000; Sonnabend et al., 2012; Sornig et al., 2013) to date.

A new IR heterodyne instrument has been developed by Tohoku University for continuous monitoring of planetary atmospheres using dedicated ground-based telescopes (60cm and 1.8m) at Mt. Haleakala, Hawaii. Remarkable aspects of the instrument are (i) an excellent system noise temperature less than 3000K at 7-10 micron wavelength, (ii) a digital FFT spectrometer as a back-end with high resolution, stability, large dynamic range, flexibility, and the absence of optical or mechanical components, (iii) frequency tuneability over a wide range provided by the use of multi- room-temperature type quantum cascade laser as local oscillators to access various molecules.

Ultra-high resolution spectroscopic measurement (R=1E7) is one of the most powerful tools to explore the planetary atmospheres with several key capabilities: (1) fully resolved molecular features to address the atmospheric temperature profiles, abundance profiles of the atmospheric compositions and their isotopes, (2) direct measurement of the mesospheric wind and temperature with high precision, (3) sensitive detection of minor trace gases, and (4) its small beam size capabilities to allow global mapping. The instrument is set on the Coude focus of the Tohoku 60cm-telescope at Mt. Haleakala in September 2014 to demonstrate the feasibility. The first Mars CO2 non-LTE emission was successfully obtained in November 2014. Its continuous operation will be started from March 2015. Main targets in the verification process are Mars and Venus. Many interesting scientific issues have been targeted and more will be addressed in the future, i.e., planets, comets, the Earth, and the Sun. Extra solar objects like stars and stellar envelopes, proto-planetary disks are also possible targets of interest.

Here the scientific capabilities and measurement sensitivities of the instrument are specifically investigated by the radiative transfer models. We use the Advanced Model for Atmospheric TeraHertz Radiation Analysis and SimUlation (AMATERASU) that is being developed in the framework of NiCT. The model is based on the Microwave Observation and LInes Estimation and REtrieval (MOLIERE) (Baron et al., 2008; Mendrok et al., 2008). We simulated the temperature/wind retrievals from a single nadir observation of CO2 absorption line at R12 970.5472 cm-1. Good temperature retrieval achieves in the rage from surface to 30km on Mars and from 65km to 95km on Venus with better than 10K precision and 10km vertical resolution. The local wind and temperature is directly derived at the middle atmosphere on Mars (75km) and Venus (110km) with 10m/s and 10K precision, respectively. These will enhance our understanding for the middle atmospheric dynamics and its fluctuations caused by the atmospheric waves from the lower atmosphere. Continuous monitoring of planetary atmospheres with its ultra-high resolution will open new insight for understanding the temporal/spatial variations in various time-scales.

Keywords: infrared, heterodyne, spectroscopy, Venus, Mars