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Heterodyne infrared spectroscopy for ultra high-spectral resolution observations of planetary atmosphere

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Most molecular bonds have strong absorptions and emissions in mid-IR region (3 to 12 um) at very specific frequencies for identifying molecules. These mid-IR fingerprints have been used in a wide variety of terrestrial and planetary atmospheric studies. In the case of the ground-based observations for planets and celestial bodies, the high-spectral resolution observations are indispensable to distinguish between the signal and the strong terrestrial absorptions. Up to now, the technology of commercial mid-IR spectroscopy has been mainly performed using Fourier-transform IR (FTIR) spectroscopy and the grating dispersive device. These direct measurements basically employ a huge system to obtain the high-spectral resolution. For, the highest possible direct detection instrument to date (e.g., TEXES/IRTF) provides a spectral resolution of 1E5, and already employs a 1 m grating.

The laser heterodyne spectroscopy is an unique powerful tool for atmospheric studies with ultra high-spectral resolution, high sensitivity, and downsizing. With the laser heterodyne spectroscopy, there is a unique instrument available to perform observations of planetary atmospheres, developed by NASA/GFSC [Kostuik et al., 1983] and University of Cologne [Sonnabend et al., 2008]. Ultra high-spectral resolution observations (1E7-8) 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. The laser heterodyne spectroscopy has been also developed by Tohoku University to observe the minor constituents in the terrestrial atmosphere from 1980s [Taguchi et al., 1990]. In recent years, the quantum-cascade laser (QCL) was applied to our heterodyne system to observe the planetary atmosphere. In particular, it will be designed for the dedicated telescope named PLANETS (2012~) at the top of the Haleakala mountain in Hawaii, for continuous monitoring of the planetary atmosphere.

In this study, we introduce (i) current status and performance evaluation of the compact heterodyne spectroscopy, (ii) interference experiments between QCL and CO2 gas laser, and (iii) an external cavity using FP-QCL and grating.

The heterodyne spectroscopy is a receiver in the mid-IR wavelength range between 8 and 12 um. The operating wavelength range of the spectrometer is determined by the tuning range of the local oscillator (LO). Currently, the distributed feedback (DFB-) QCLs at 9.6 and 10.3 um, and the Fabry-Perot (FP-) QCL at 8.0 um can be operated. These QCLs were manufactured by HAMAMATSU Photonics. Using FP-QCL with combination with an external cavity provides wider tuneability by a factor of up to 100, greatly expanding the accessible wavelength range and multi-detections. The QCL is mounted in a peltier cooling box, which can be operated in a room temperature. The spectral resolution is expected to be better than 1E7 when the stabilizer of the wavelength (e.g., diplexer) is applied, with a band width of two times 1 GHz (10 km/s at 10 um) with digital FFT spectrometer manufactured by Agilent. As for the sensitivity, in case of the University of Cologne, the system noise temperature could be lower than 3000 K at 10 um, or at only a factor of two above the quantum limit [Sonnabend et al., 2008]. Currently, we evaluate the system noise temperature ,reducing the standing waves and external noise. Continuous monitoring using this ultra high-spectral resolution observations, the understanding the evolution of the planetary atmosphere is expected to be significantly accelerated.

Keywords: heterodyne, spectroscopy, infrared, quantum-cascade laser