Scientific capabilities and measurement sensitivities of the IR heterodyne spectroscopy

A new IR heterodyne instrument is developed for continuous monitoring of planetary atmospheres using dedicated telescope at Mt.Haleakala.

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Advantage of MILAHI (R>1E6) on T60

Ultra-high resolution spectroscopy is one of the most powerful tool to explore the planetary atmospheres with several key capabilities:

1. **Fully resolved molecular features** for temperature /wind profiles, abundance profiles of the atmospheric compositions and its isotopes
2. **Direct measurement of the mesospheric wind / temperature** with high precision
3. **Sensitive detection of minor trace gases**
4. Small beam size for **global mapping**
5. **Continuous monitoring** for time variations

Mid-IR LAser Heterodyne Instr. (MILAHI)

$$R_{TOA} = \varepsilon B(T_{surf})e^{-\tau} + R_{UW}$$

$$I_{het} = R_{TOA} \otimes R_{LO}$$

$$I_{het} = I_{DC} + I_{IF} = P_S + P_L + 2\sqrt{P_S P_L} \cos(2\pi\gamma_{IF}t - \varphi)$$

IR (30THz) flux from the planet through its atmosphere, is **combined with LO**, and focused on photo mixer. Output is in **radio region** (1GHz) of the electromagnetic spectrum.

Earth Spectra

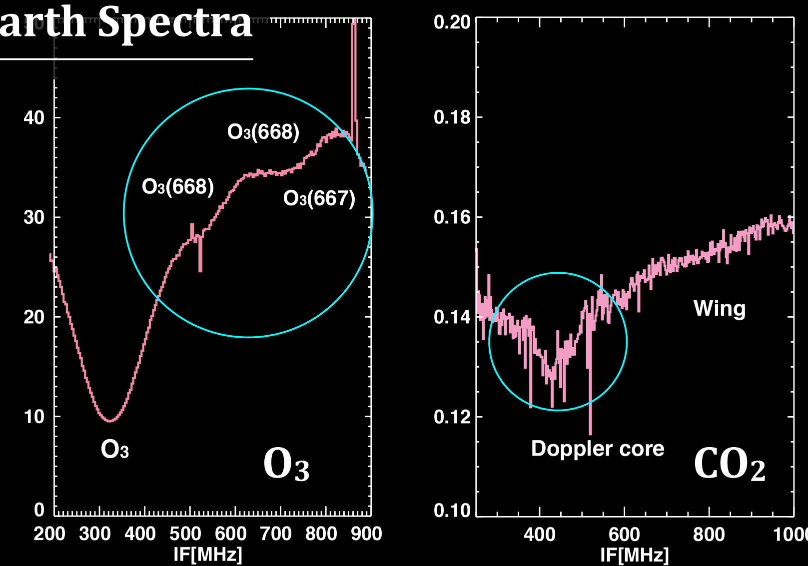


Fig. Observed terrestrial CO_2 with T60 reduced sunlight at 970.532 cm^{-1} (10min integ.) [right], and O_3 spectra with coelostat in the lab at 1043.864 cm^{-1} (5min integ.).

Fully resolved molecular feature can be obtained.

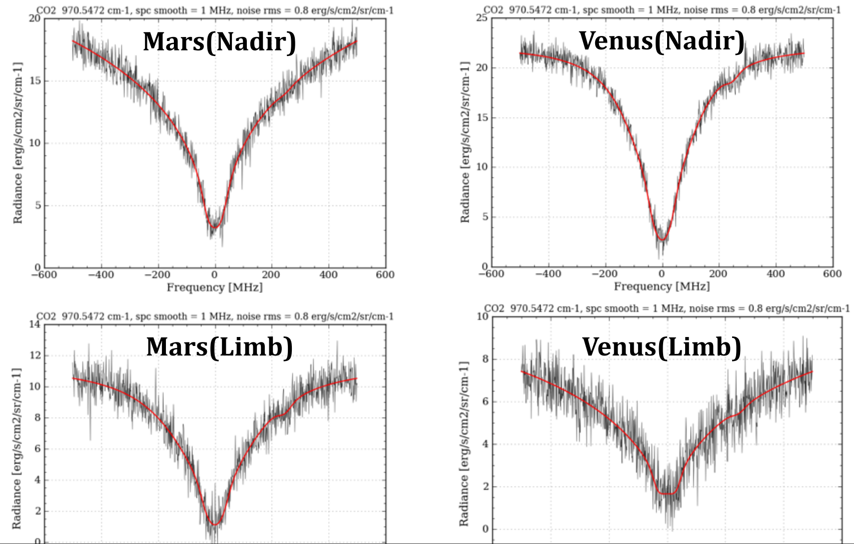


Fig. Synthetic spectra of Mars and Venus CO_2 absorption. Upper panels assumed by nadir geometry, and bottom panels assumed by limb geometry using RT.

1.Temperature profile (Venus Nadir)

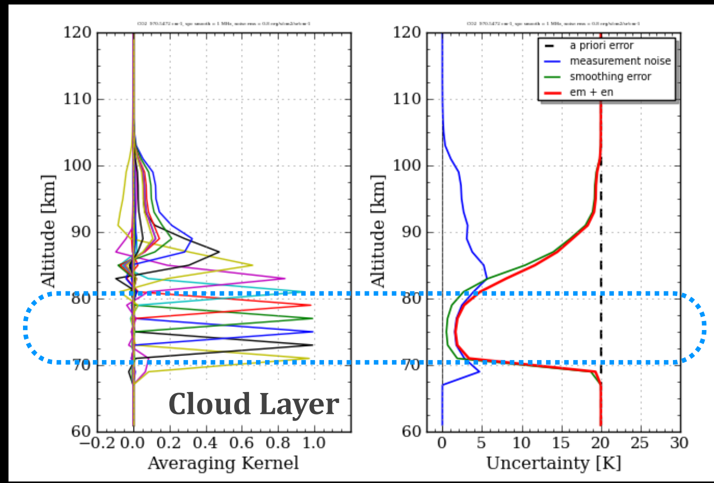


Fig. The retrieved averaging kernel and uncertainty for T-profile.

Excellent retrieval is achieved from 70km to 80km on Venus with better than 5K precision and 2km vertical resolution.

1.Wind profile (Venus Limb)

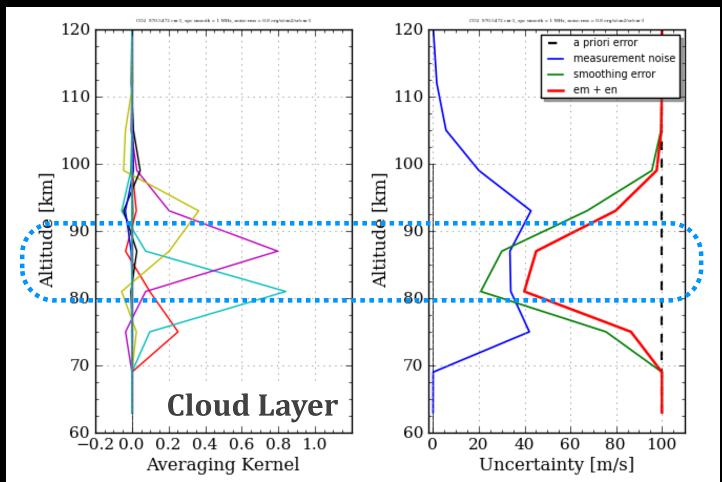


Fig. The retrieved averaging kernel and uncertainty for T-profile.

Good retrieval is achieved from 80km to 90km on Venus with better than 40m/s precision and 10km vertical resolution.

1.Temperature profile (Mars Nadir)

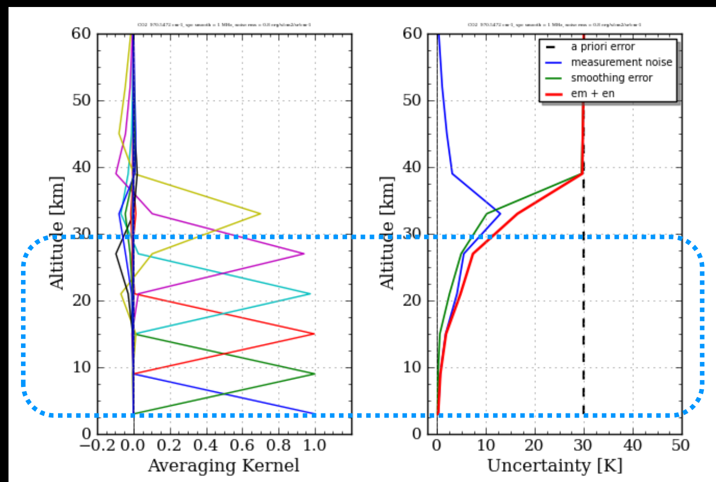


Fig. The retrieved averaging kernel and uncertainty for T-profile.

Good retrieval is achieved from surface to 30km on Venus with better than 10K precision and 10km vertical resolution.

2.Mesospheric CO_2 non-LTE emission

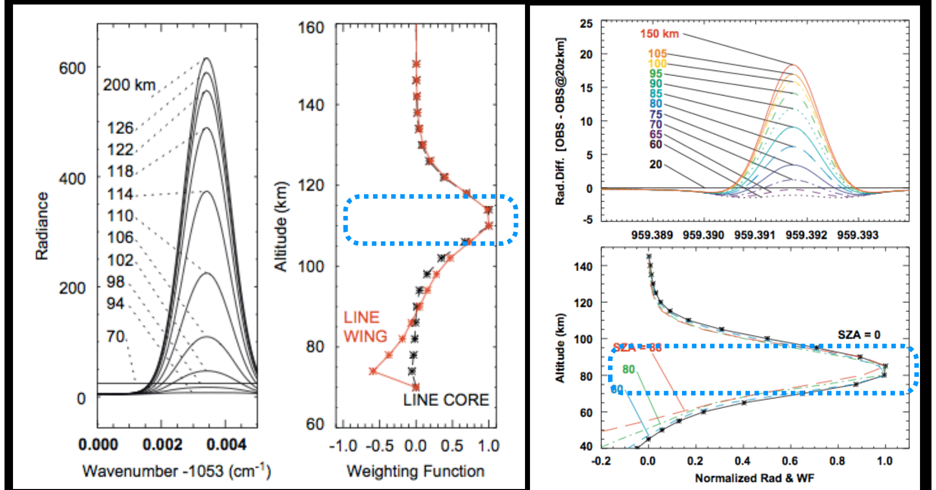


Fig. Simulated CO_2 non-LTE emission and its altitude [Lopez-Valverde et al., 2011].

Direct measurements of wind/T at 110km(V) and 80km(M).

2.CO_2 non-LTE emission (Venus)

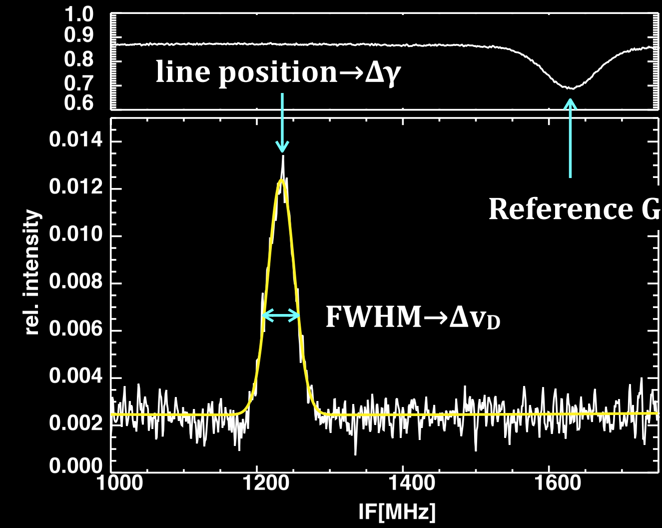
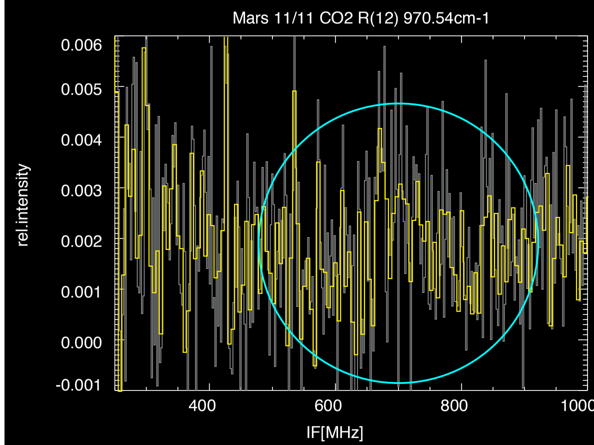


Fig. CO_2 non-LTE emission observed by Cologne IR heterodyne in June 3, 2009.

Excellent accuracy for wind(±11m/s) and temp.(±12K)(高見).

2.CO_2 non-LTE emission (Mars)



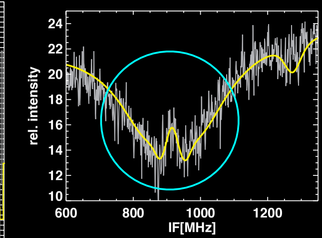
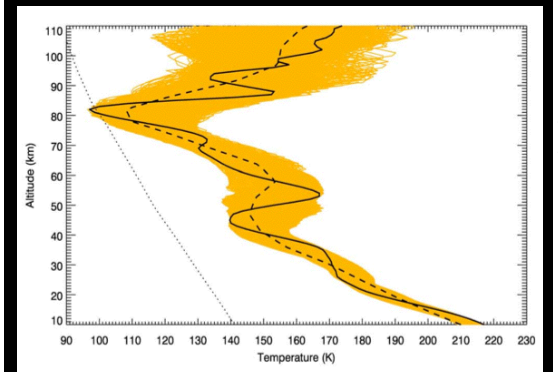


Fig. Observed Martian CO_2 non-LTE emission spectrum by Cologne IR heterodyne spectrometer in March 12, 2007. [Sornig Manuela]

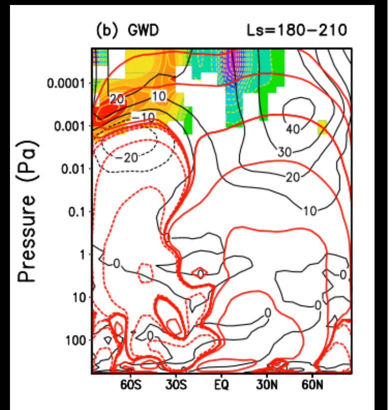
Fig. Observed Martian CO_2 non-LTE by MILAHI with T60 (10min integ.). BW=1GHz, 2MHz resolution in Nov. 11, 2014.

The instrument is already set on the Coude focus of T60. First detection of Martian non-LTE emission was achieved.

2.Dynamics in the mesosphere



[Spiga et al., 2010]

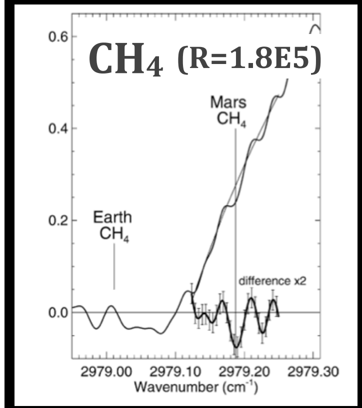


[Medvedev et al., 2010]

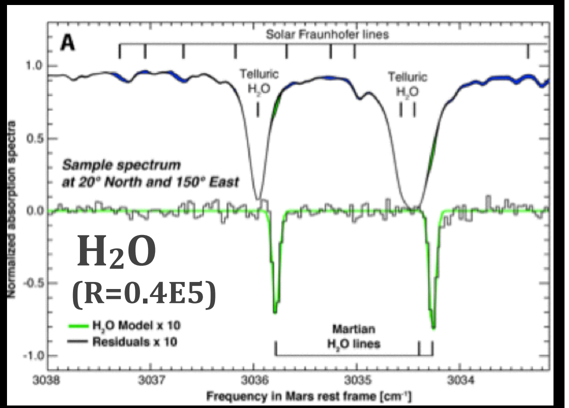
Fig. Simulated variable nature of the thermal profiles on Mars caused by GWs in the lower atmosphere (left). Simulated GW effects on the mesospheric heating (right).

Significant effects of GW on the upper atmosphere. Key issue for the coupling between lower and upper atmospheres.

3.Trace Gases and isotopes



[Krasnopolsky, 2004]

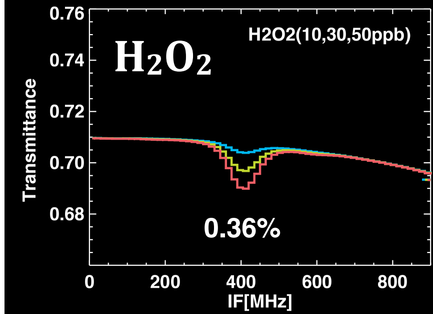


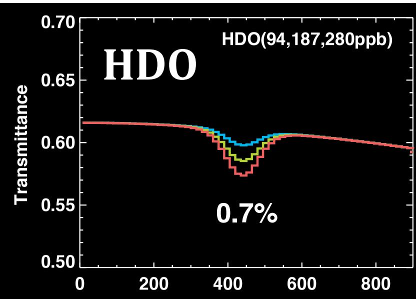
[Villanueva et al., 2009]

Fig. Examples of the planetary atmospheric absorptions, migrated by terrestrial ones.

Using MILAHI, detection of trace gases is performed without any ambiguity by migrating with terrestrial absorption.

3.Trace Gases (Synthetic spectra)





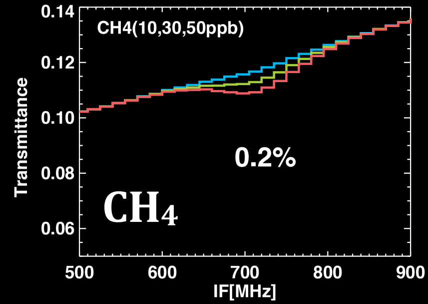
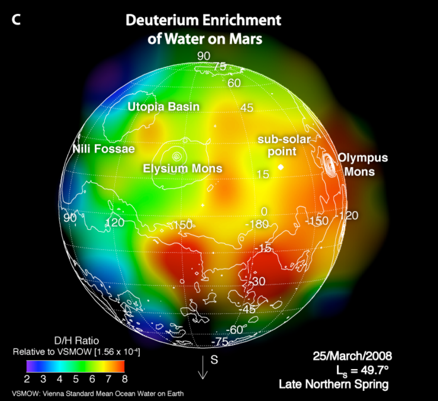


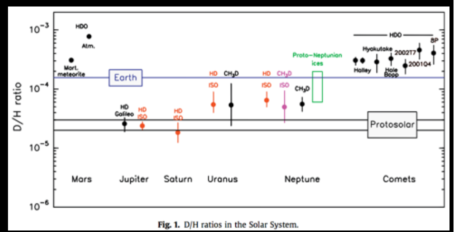
Fig. Synthetic spectra of the Martian HDO, H_2O_2, and CH_4 at 1295.00, 1295.91, 1294.42 cm^{-1}. Doppler shift is assumed to be -15km/s. 33MHz binning.

Precise detection of H_2O_2 10ppb with 6hr, CH_4 18hr, and 1 VSMOW HDO with 1.5hr integration time.

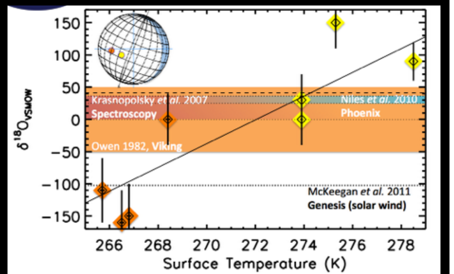
3.Isotopes (Variations)



[Villanueva et al., 2009]



[Hartogh et al., 2010]

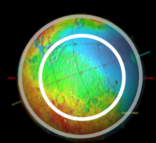


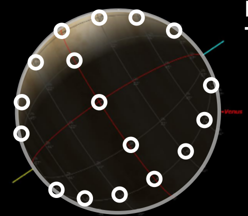
[Livengwood et al., 2014]

100‰ accuracy for H_2O, CO_2 isotopes variations.

4.Beam size on Sep. 2015

Mars
Vd = +3.3 km/s
S-O-T = 28°
Diam. = 3.8”
Total N = 12





Venus
Vd = +11.02 km/s
S-O-T = 36°
Diam. = 42.0”
Total N = 15

Tab. Spatial resolution (Beam size of MILAHI v.s. Apparent size of targets)

LO	Spectral bands (cm-1)	Beam size (60cm)	Beam size (1.8m)
1	968-973 (10.3 μm)	3.54”	1.18”
2	1043-1048 (9.6 μm)	3.30”	1.10”
3	1230-1245 (8.0 μm)	2.76”	0.92”
4	1293-1297 (7.7 μm)	2.64”	0.88”

The global distributions can be investigated in Venus with 60cm telescope.

Summary

The scientific capabilities and measurement sensitivities of the MILAHI are specifically investigated by the radiative transfer model.

- **Good temperature retrieval is achieved from surface to 30km on Mars with better than 10K precision and 10km vertical res., and from 70km to 80km on Venus with better than 5K precision and 2km vertical res.. Wind retrieval is achieved from 80km to 90km with 40m/s uncertainty and 10km vertical res..**
- **The local wind and temp. is directly derived at the middle atmospheres with 11m/s, 12K accuracy.**
- **Detection of trace gases is performed without any ambiguity by migrating with terrestrial absorption.**