Search of CH_4 on Mars with SUBARU/IRCS and MEX/PFS limb data
: Preliminary results from the observations using SUBARU/IRCS on January and validation of the radiative transfer modeling for PFS limb observations

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Abstract

We observed Martian atmosphere to investigate CH_4, H_2O, and HDO on 1 December 2011, 4-5 January 2012, and 12 April 2012 using SUBARU/IRCS. Owing to the wide spectral coverage of IRCS, we could measure the five spectral bands simultaneously; 2.94-3.01 μm, 3.01-3.18 μm, 3.28-3.36 μm, 3.49-3.57 μm, and 3.72-3.81 μm. The measured spectra appears a lot of Martian CO_2 isotope lines, terrulic H_2O lines, terrulic HDO lines, and terrulic CH_4 lines. In order to detect the tiny Martian H_2O, HDO and CH_4 lines, we are developing a model to separate the contributions from Martian and telluric lines. We will verify the existence of CH_4 on Mars using multiple lines, investigate CH_4 abundances on possible source areas for constraint of its source, and investigate distribution of H_2O/HDO ratios for understanding of water cycle on Mars.

Furthermore, we begin to attempt detection of CH_4 and the other trace gases with MEX/PFS limb data. For that, we have been developing a radiative transfer code which includes multiple scattering for Martian limb geometry. In order to validate our code, we compared our synthetic spectra in nadir geometry with the spectrum by the other model which has been widely used for analysis of PFS nadir data. We concluded that the difference between them is small offset (below 3%) in the spectral range between 3007 and 3022 cm^{-1}.

1. 2011-2012 observing campaign using SUBARU/IRCS

It is almost certain that Mars was "wet and hot" planet in the past. However, the present Mars is a "dry and cold" planet. Where was a large amount of a liquid water gone? One possible candidate is water ice trapped underground. Investigation of HDO/H_2O rations in the atmosphere can constrain the water cycle on Mars because the ratios vary with condensation-sublimation processes of water (e.g., [1]).

Moreover, the recent discovery of CH_4 on Mars has led to much discussion on its source and sink [2,3]. It is suggested that the release of CH_4 (whether abiotic or biotic) is closely linked to the presence of water [4]. It is therefore important to establish the HDO/H_2O in water released with CH_4 on Mars because the HDO/H_2O ratio is contributed by a surface-atmosphere interaction. However, the previous observations of HDO/H_2O and CH_4 are very limited. Therefore, we observed CH_4, H_2O, and HDO simultaneously using SUBARU/IRCS.

We observed Mars using SUBARU/IRCS on 1 December 2011, 4-5 January 2012, and 12 April 2012. The observation of April is simultaneous with MEX/PFS. **Table 1** is summary of our observing campaigns in 2011-2012 periods.

Our observations covered possible source areas of CH_4, i.e. the areas where the extend plumes of CH_4 were detected by previous ground-based and MEX/PFS observations [2,3] and mud volcanism areas suggested around the mounds in Acidalia Planitia and Utopia/Isidis pitted cones (UIPC) [5,6]. In the terrestrial case, mud volcanism vents major quantities of CH_4 (10×10^6 tons/year). Moreover, it is remarkable that the areas where the extended plumes of CH_4 were detected are on the same outer ring of the Isidis basin that intersects UIPC [3]. The mud volcanism on Mars might contribute to the release of CH_4.

The slit was put along the E-W direction on 4 January 2012 and along the N-S direction on the other days. Therefore, we can derive the latitudinal and local time (or longitudinal) distrobution of HDO/H_2O ratio and CH_4 amount in the northen spring and summer. Especially, the observation in April will be the first measurement of HDO/H_2O distribution in the northern summer season.

The IRCS is an echelle spectrometer with high spectral resolution (R=20,000) at SUBARU telescope (8.2m) in Maunakea observatory [7]. We observed Mars with 6.69" ×0.14" slit in the five spectral bands, 2.94-3.01 μm (order-19), 3.01-3.18 μm (order-18), 3.28-3.36 μm (order-17), 3.49-3.57 μm (order-16), and 3.72-3.81 μm (order-15). One of the advantages of IRCS is the wide spectral coverage. The spectral ranges have multiple lines of CH_4, H_2O, HDO and CO_2 isotopes. **Fig. 1** shows an example of measured spectra in the five spectral bands of IRCS. The observed spectrum in order-19 and order-18 consists mostly of telluric H_2O lines, the spectrum in order-17 consists both telluric H_2O and CH_4 lines, the spectrum in order-16 mostly of telluric CH_4 lines, and the spectrum in order-15 consists Martian CO_2 isotope and telluric HDO lines. Owing to the wide spectral coverage, we could performed absolute simultaneous observations of H_2O, HDO and CH_4 for the first time. Using multiple CH_4 lines can improve the reliability of our results. This is because it was pointed out that the previous ground-based observations had a large uncertainty since they used single band of Martian CH_4 included the terrestrial $^{13}CH_4$ lines [8]. It is crucial important to verify the detection of Martian CH_4.

In order to detect the tiny Martian H_2O, HDO and CH_4 lines, contributions from Martian and telluric lines have to be separated. For that, we are developing a model to calculate synthetic spectrum observed with IRCS. Because width of terrulic line is enough wide than instrumental line shape of IRCS, transmittance of non-saturated terrulic line is given by,

$$t_E(x_i) = e^{-\eta_E N_E S_E f(x_i - x_E)},$$

where x_i is pixel-position (which corresponds to wavenumber), η_E is the observing airmass of terrestrial atmosphere, N_E is the column density of the terrestrial gas, S_E is the terrestrial line intensity derived from HITRAN database, x_E is the line center of terrestrial absorption and *f(x)* is line shape function (e.g., Lorentizan function). While, since width of Martian H_2O, HDO, and CH_4 lines are narrow than instrumental line shape of IRCS, the transmittance is given by,

$$t_M(x_i) = \int_{x_i - \frac{1}{2}}^{x_i + \frac{1}{2}} \frac{W}{d} \times ILS(x_i - x_M) dx_i.$$

where *d* is the dispersion of IRCS, x_M is line center of the Martian line, *ILS(x)* is the instrumental line shape of IRCS, and *W* is so-called equivalent width:

$$W = \int_0^\infty \frac{I_0 - I_\lambda}{I_0} d_\lambda$$

where I_λ and I_0 are the intensities inside and outside the line, respectively. Since the Martian trace gases are optical thin, the equivalent width is give by,

$$W = \eta_M N_M S_M,$$

where η_M is the observing airmass of Martian atmopshere, N_M is the column density of the Martian gas, and S_M is the Martian line intensity derived from HITRAN database.

The expected IRCS spectrum is give by,

$$F(x_i) = (ax_i + b) \times t_E(x_i) \times t_M(x_i),$$

where *a* and *b* are scaling factors. We will retrieve the column density of H_2O, HDO, and CH_4 by comparison between the synthetic spectra and the measured spectra.

2. Development of radiative transfer model for MEX/PFS limb observation

Vertical profiles of the trace gases are also crucial for their chemistry and transportation. For example, a recent study reports that the vertical profile of Martian H_2O shows a super-saturation [8], which is important to understand water cycle. However, the vertical profiles of the trace gases is still not well-investigated because it is difficult to retrieve it by a ground-based observation or a space-born nadir observation. Limb observations of MEX/PFS is a powerful tool to retrieve vertical profiles of H_2O, CO, and CH_4. However, at the moment, there are no radiative transfer codes with multiple scattering for Martian limb observations. Therefore, we have developed the radiative transfer code for PFS limb observations.

We adapted the SARTre model, a radiative transfer code which includes multiple scattering in limb geometry observations developed for the terrestrial atmosphere [10], to be applied for the Martian atmosphere. In order to validate our model, we performed comparison of synthetic spectra by our model and ARS model [11], which is widely used in PFS Nadir data analysis, in the spectral range between 3007 and 3022 cm^{-1}. **Fig. 2** shows the synthetic spectra by SARTre and ARS with dust, water ice, and H_2O in nadir geometry. We conclude that the difference between the results of the two models is very small offset (below 3%) in the entire spectral range. As a second step, we will compare our synthetic spectra in limb geometry with a Monte Carlo model.

Acknowledgements

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Figures and Table

Table 1: Summary of SUBARU/IRCS observations

Observing date (HST)	(a) 2011/12/1 AM 4:00- AM 5:30 (1.5h) (b) 2012/1/4 AM 1:00- AM 6:00 (5h) (c) 2012/1/5 AM 1:00- AM 6:00 (5h) (d) 2012/4/12 PM 8:00- AM 2:30 (4h) [joint observation with PFS]
Diameter	(a) 7” (b,c) 9” (d) 11”
Doppler shift	(a) -16km (b,c) -15km/s (d) +11km/s
Ls	(a) 37° (b,c) 52° (d) 96°
Slit direction	(a,c,d) N-S direction (b) E-W direction
Target Areas	(a) North pole [70-90N] (b) Utopia/Isidid [20-40N, 250-270W] Nili Fossae [15-30N, 270-290W] Sytris Major [-15-15N, 270-290W] (c) Utopia/Isidid Nili Fossae Sytris Major,North pole (d) Acidalia Planitia [30-60N, 0-60W] Terra Sabae [-30-30N 300-330W] North pole

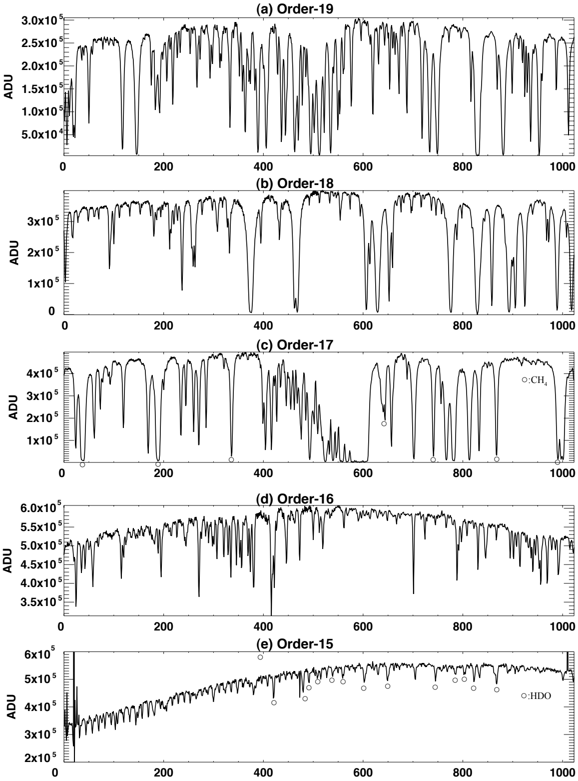

Figure 1: An example of measured spectrum of IRCS. It has the five spectral bands, 2.94-3.01 μm (order-19), 3.01-3.18 μm (order-18), 3.28-3.36 μm (order-17), 3.49-3.57 μm (order-16), and 3.72-3.81 μm (order-15). The spectrum was observed on 5 January with 5-min integration and without binning. The almost all strong features in order-19 and order-18 are telluric H_2O lines. Spectrum in order-17 contains strong telluric CH_4 and H_2O lines, and the circular symbols in Fig. (c) represents the H_2O lines. The almost all strong features in order-16 are telluric CH_4 lines. Spectrum in order-15 appears Martian CO_2 isotope and telluric HDO lines, and the circular symbols in Fig. (e) represents the HDO lines.

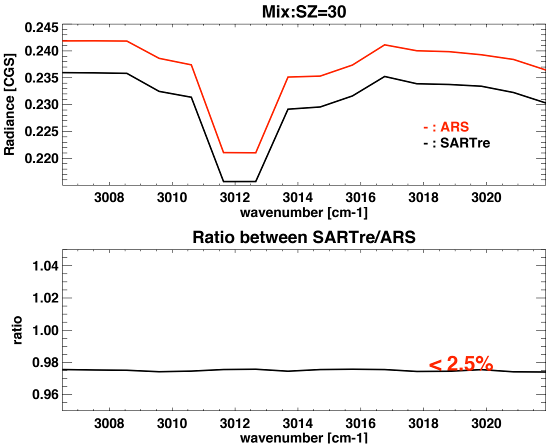

Figure 2: Synthetic spectra by SARTre (black curve) and ARS (red curve) in the spectral range between 3007 and 3022 cm^{-1} (top) and the ratio between by SARTre and ARS (bottom). The phase angle is considered as 30 degrees. We consider both water ice and dust as aerosols and water H_2O as gases in the Martian atmosphere. These vertical distributions uses typical ones. The absorption feature at 3012 cm^{-1} is contributed by solar line and Martian H_2O lines. The difference between SARTre and ARS is small offset (below 3%).