CH$_4$ and HDO/H$_2$O distributions on Mars observed by SUBARU/IRCS

Shohei Aoki$^{a,b}$, Hiromu Nakagawa$^a$, Yasumasa Kasaba$^a$, Hideo Sagawa$^c$, and Marco Giuranna$^b$

$^a$Department of Geophysics, Tohoku University, Sendai, Miyagi 980-8578, Japan.
$^b$Istituto di Astrofisica e Planetologia Spaziali (IAPS), Via del Fosso del Cavaliere 100, 00133 Roma, Italy.
$^c$National Institute of Information and Communications Technology, 4-2-1, Nukui kita, Koganei, Tokyo 184-8795, Japan

Abstract

We present distributions of D/H ratio in water vapor at the northern spring by ground-based observations. Although it is suggested that Mars has a drastic water cycle with sublimation-condensation process, previous observations of water vapor could not discriminate between the sublimation-condensation process and the atmospheric dynamics. Monitoring of D/H ratio in water vapor is a powerful tool to distinguish the processes because the lighter H$_2$O vapor preferentially sublimate whereas the heavier HDO vapor preferentially condense due to the difference in their vapor pressures. Previous observations by the IRTF/CSHELL found that the HDO/H$_2$O ratio varied between about 2 to 8 (relatively to Standard Mean Ocean Water (SMOW)) depending on location and local time at the northern spring (Villanueva et al., 2008; Novak et al., 2011). However, they could not perform simultaneous observations of H$_2$O and HDO due to the narrow spectral coverage of the CSHELL. The SUBARU/IRCS can observe H$_2$O and HDO features simultaneously owing to the wide spectral coverage. We investigated D/H ratio in water vapor depending on latitude and longitude using the IRCS. The observations were performed during the northern spring in the Mars Year 31 ($L_s$=52.4° and $L_s$=52.9°). The retrieved values of H$_2$O/HDO ratio are generally consistent with the previous reports. The latitudinal distribution of HDO/H$_2$O ratio exhibits maximum at sub-solar latitudes (~20 N). This gradient has an agreement with the previous result reported by Novak et al. (2011), and suggests that rich condensation of HDO vapor at high latitude and equatorial region. Meanwhile, the longitudinal distributions of HDO and H$_2$O abundances show the local enhancement over Arabia (~330W). However, the HDO/H$_2$O ratio is not appeared clear variation over the region. It suggests that the local enhancement is controlled by atmospheric dynamics. In addition, we performed similar observation during the northern summer ($L_s$=96.2°). From the preliminary analysis of the measurement, we find enhancement of HDO abundances around the north polar cap for the first time.
**Introduction : Is Mars water-rich planet?**

* Recent observations suggest rich water at the polar caps and underground.

![Mars surface and polar caps](image)

![H2O ice deposits](image)

**Introduction : HDO/H2O GCM simulation**

* A GCM simulation suggests that HDO/H2O ratios range between 2 to 5 due to condensation

![HDO/H2O distribution](image)

**Introduction : Water cycle on Mars**

* Recent observations show the water cycle in the atmosphere.

![Water cycle diagram](image)

**Motivation : With HDO/H2O observations, sublimation-condensation process in water (including surface-atmosphere interaction) is investigated**

\[ \frac{\langle \text{HDO} \rangle}{\langle \text{H}_2\text{O} \rangle} = 1.43 \]

(Montmessin et al., 2008)

The subducted vapor pressure of HDO is less than that of H2O.

**Key questions**

- **Goal : Understanding of sublimation-condensation process in water (including surface-atmosphere interaction)**
  - Latitudinal distribution of HDO/H2O at different season?
  - Longitudinal distribution of HDO/H2O?
  - Local-time dependence of HDO/H2O?

Remote-sensing by high-resolution NIR spectrometer from space-craft is the best way to investigate these. However, there are no such instruments. NOMAD/TGO will be able to do it (it will be able to obtain 3-D HDO/H2O map by Nadir & Solar-occultation observation model). Ground-based observation with high-resolution NIR spectrometer is only way at the moment. We investigated HDO/H2O on Mars using SUBARU/IRCS. It can obtain longitudinal or latitudinal distribution over the planet at the same time.

**Instruments: SUBARU / IRCS**

- IRCs has been designed to deliver 6 fraction limited images from 2 to 5 μm as well as providing spectropolarimetry with grisms and a cross-dispersed echelle. The camera can also be used as a kai viewer for the activities.

**HDO/H2O analysis**

We use HDO lines at 3035 cm⁻¹ and HDO line at 2677 cm⁻¹ because these lines are strong, not saturated, and does not have any contaminations. The other terrestrial lines (O3, N2O, CH4, and H2O isotopes etc), Martian CO2 lines, and solar lines.

- 1.24-3.01 μm: telluric HDO lines
- 2.3.10-3.18 μm: Martian CO2 lines
- 3.7-3.8 μm: telluric HDO lines

![IRCS spectrum](image)

Further investigation of HDO/H2O is indispensable.
2011-2012 Observing campaign by SUBARU/IRCS

Table: Summary of SUBARU/IRCS observations during 2011-2012 periods. The observations aim to investigation of HDRO/H2O, O3 lines, and CHN distributions.

<table>
<thead>
<tr>
<th>Date</th>
<th>Number of nights</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 2011/7/1</td>
<td>4 nights</td>
<td>Investigation of HDRO/H2O latitudinal details</td>
</tr>
<tr>
<td>(b) 2011/7/8</td>
<td>4 nights</td>
<td>Investigation of HDRO/H2O latitudinal details</td>
</tr>
<tr>
<td>(c) 2011/7/15</td>
<td>4 nights</td>
<td>Detailed observation of HDRO/H2O latitudinal details</td>
</tr>
<tr>
<td>(d) 2011/7/22</td>
<td>5 nights</td>
<td>Target observation of the potential CHN sources</td>
</tr>
<tr>
<td>(e) 2011/7/29</td>
<td>5 nights</td>
<td>Target observation of HDRO/H2O latitudinal details</td>
</tr>
<tr>
<td>(f) 2011/8/5</td>
<td>5 nights</td>
<td>Target observation of HDRO/H2O latitudinal details</td>
</tr>
<tr>
<td>(g) 2011/8/12</td>
<td>5 nights</td>
<td>Target observation of HDRO/H2O latitudinal details</td>
</tr>
<tr>
<td>(h) 2011/8/19</td>
<td>5 nights</td>
<td>Target observation of HDRO/H2O latitudinal details</td>
</tr>
<tr>
<td>(i) 2011/8/26</td>
<td>5 nights</td>
<td>Target observation of HDRO/H2O latitudinal details</td>
</tr>
</tbody>
</table>

Observations and Method of analysis

- We observed Mars using IRCS (a near-infrared echelle spectrometer) on 4 nights during 2011-2012 periods.
- Investigation of HDRO/H2O latitudinal distribution at different seasons.
- The distribution is explained by condensation in the atmosphere.
- The mean value of HDRO/H2O is 3.3 ± 1.0. It is slightly smaller than the values by previous observations.
- The distribution is shown in the figure.

Latitudinal distribution at Ls = 52° (LT = 13-15)

- The HDRO amounts lower is consistent with the values derived from Mars Climate Database (MCID).
- The values of HDRO/H2O are maximum at middle latitudes (20-40° N). The distribution would be explained by condensation in the atmosphere.
- The mean value of HDRO/H2O is 3.3 ± 1.0. It is slightly smaller than the values by previous observations.
- The distribution is shown in the figure.

Latitudinal distribution at Ls = 37°

- Since there's high humidity during observations on 12/1 and 4/12, Martian HDRO amounts could be defined by SUBARU. Here, I use MCD model for HDRO/H2O analysis.
- The values of HDRO/H2O ratios are maximum at middle latitudes (20-40° N) and around 10° S. The distribution would be explained by condensation in the atmosphere.
Latitudinal distribution at Ls = 96°

Longitudinal distribution at Ls = 52°

Summary

- Motivation: Investigation of sublimation-condensation process in water on Mars with HDO/H2O observations. We performed observation of its latitudinal distribution and local time dependence using SUBARU/IRCS.
- Latitudinal distribution: Our observations at Ls=52 and Ls=37 show that the values of HDO/H2O ratios decrease from the sub-solar latitude (~20°N) to north-pole and low-latitude together with HDO and H2O amounts. It would be basically explained by condensation in the atmosphere.
- Local-time / Longitudinal distribution: A strong longitudinal distribution of HDO/H2O ratios appears around 240 degrees or 16-18 h. A clear longitudinal distributions of HDO and HDO amounts appear. The further investigation of the distributions are one of the important future works.