Latitudinal and seasonal variations of $O_2$ on Mars using Herschel/HIFI

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Objective of the study

• With a mean mixing ratio above 0.1%, molecular oxygen is, after nitrogen and argon, the most abundant minor species. Still, its abundance and seasonal variations remain poorly studied, because of the weakness of its spectroscopic signatures. Oxygen was first detected at 0.76 µm by Barker (1972) and Carleton and Traub (1972), with a mixing ratio of 1300 ppm.
• A new disk-averaged measurement of 1400 ± 120 ppm has been recently inferred by Hartogh et al. (A&A 521, id. L49, 2010) using high-resolution heterodyne spectroscopy at 774 GHz with the HIFI instrument aboard Herschel (April 2010, Ls = 76°).
• As a non-condensible species, oxygen on Mars, like CO, is expected to show spatial and temporant variations, but these measurements have not been performed yet on O₂.
• We have been using HIFI aboard Herschel to study the latitudinal variations of O₂ on Mars for two different seasons, Ls = 47° (Dec. 23, 2011) and Ls = 108-115° (May 09-25, 2012). In addition, HDO and H₂¹⁸O transitions have been measured simultaneously for a retrieval of D/H. ¹³CO and C¹⁸O transitions have been recorded simultaneously to infer CO mixing ratio and check the consistency of the GCM thermal profile.
• The present report describes the analysis of the O₂ and CO data.
The data set

Dates:
Dec 22, 2011 – Ls = 47°, Mars Diam = 8.3 arcsec
May 25, 2011 – Ls = 115°, Mars Diam = 8 – 9 arcsec

Transitions:
Simultaneous measurements:
- $^{13}$CO 1870.141 GHz, C$^{18}$O 1863.039 GHz, O$_2$ 1870.018 GHz
- O$_2$ 1812.405 GHz, HDO 1818.519 GHz
- HDO 1625.408 GHz, H$_2$O$^{18}$O 1633.483 GHz

Herschel FOV: 11.3 arcsec @ 1870 GHz, 12.9 arcsec @ 1633 GHz

Observation sequence:
For each period, three observations were successively recorded, centered along the central meridian, at the south limb, the center and the north limb.

Total observing time: 27 hours
Data analysis

• Strong ripples are present in the raw data because Mars is a strong continuum source (Hartogh et al. A&A 521, id.L48, 2010)
• Ripple has been corrected from the known instrument standing wave frequency by removing sinusoidal baselines
• N-S offsets have been inferred using a radiometric model of Mars
• RT calculations have been made for the exact offsets of the observations, using the EMCD-GCM temperature profiles, for different values of the CO and O₂ mixing ratios
• Best fits are shown in the next figures, for the $^{13}$CO and $^{18}$O lines and for the two O₂ lines, for the 3 disk positions and the two seasons.
Herschel/HIFI data after ripple correction

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>C18O</th>
<th>13CO</th>
<th>O2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1863.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1870.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1870.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1818.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1812.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- C18O: 0.0 +7.2
- 13CO: 0.0 +1.6
- O2: 0.0 -4.0
- HDO: 0.0 +7.7
- 02: 0.0 +2.0
- O2: 0.0 -3.7

 Velocity (km/s)
HIFI/Herschel, Dec 22, 2011, South – Ls = 47° - CO = 1100 ppm

13CO Dec 11 South Ts = 235 K, CO = 1100 ppm

C18O Dec 11 South Ts = 235 K, CO = 1100 ppm
HIFI/Herschel, Dec 22, 2011, South – Ls = 47° - O₂ = 1600 ppm

O₂ 1812 GHz Dec 11 South Ts = 235 K, O₂ = 1600 ppm

O₂ 1870 GHz Dec 11 South Ts = 235 K, O₂ = 1600 ppm
HIFI/Herschel, Dec 22, 2011, Center – Ls = 47° - CO = 1000 ppm
HIFI/Herschel, Dec 22, 2011, Center – Ls = 47° - O₂ = 1600 ppm

O₂ 1812 GHz Dec 11 Center Ts = 240 K, O₂ = 1600 ppm

O₂ 1870 GHz Dec 11 Center Ts = 240 K, O₂ = 1600 ppm
HIFI/Herschel, Dec 22, 2011, North – Ls = 47° - CO = 1000 ppm

13CO Dec 11 North Ts = 242 K, CO = 1000 ppm

C18O Dec 11 North Ts = 242 K, CO = 1000 ppm
HIFI/Herschel, Dec 22, 2011, North – Ls = 47° - O$_2$ = 1600 ppm
25 May 2012 Data – Thermal profiles

Thermal profiles (GCM)

'prof_sud_1jun12.txt' using 2:1
'prof_moy_1jun12.txt' using 2:1
'prof_nord_1jun12.txt' using 2:1
HIFI/Herschel, May 25, 2012, South – Ls = 115° - CO = 1100 ppm

13CO May12 South Ts = 230 K, CO = 1100 ppm

C18O May12 South Ts = 230 K, CO = 1100 ppm
HIFI/Herschel, May 25, 2012, South – Ls = 115° - O_2 = 1600 ppm
HIFI/Herschel, May 25, 2012, Center – \( Ls = 115^\circ \) - \( CO = 1000 \) ppm
HIFI/Herschel, May 25, 2012, Center – Ls = 115° - O₂ = 1600 ppm
HIFI/Herschel, May 25, 2012, North – Ls = 115° - CO = 1000 ppm

13CO May12 North Ts = 245 K, CO = 1000 ppm

C18O May12 North Ts = 245 K, CO = 1000 ppm
HIFI/Herschel, May 25, 2012, North – Ls = 115° - O₂ = 1600 ppm

O₂ 1812 GHz Dec 11 North Ts = 245 K, O₂ = 1600 ppm

O₂ 1870 GHz Dec 11 North Ts = 245 K, O₂ = 1600 ppm
Conclusions

- Best fits are obtained for the following mixing ratios of CO and O$_2$ (ppm):

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th></th>
<th>O$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>C</td>
<td>S</td>
</tr>
<tr>
<td>Dec. 2011 (Ls = 47°)</td>
<td>1000</td>
<td>1000</td>
<td>1100</td>
</tr>
<tr>
<td>May 2012 (Ls = 115°)</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

- For both seasons, there is no evidence for a latitudinal variation in the mixing ratios of CO and O$_2$

- There is a systematic discrepancy in the fits of the CO lines, with the synthetic $^{13}$CO line being stronger than the data and the synthetic C$^{18}$O line being weaker
  - Possible origin: Uncertainty in USB/LSB gains

- For both CO and O$_2$, the inferred mixing ratios tend to be larger than measured by Hartogh et al. (A&A 521, id. L48 and id. L49, 2010) for Ls = 77°
  - Possible origin: Change in T(z) profile? Seasonal effect?