Charaterization of tenuous atmospheres by VIS-IR limb observations
Hints for future Jupiter system missions

Davide Grassi
IFSI-INAF, Roma
Overviews

• Review of tenuous atmosphere observations by IR spectro-imagers
  • Galileo NIMS
  • Cassini VIMS
  • Venus express VIRTIS

• Species of interest

• Possibilities for future Jupiter system missions
Rationale for IR observations

- IR spectroimagers are common payload components of planetary missions for their wide range of applications.
- Instruments are usually optimized for surface observations. Tenuous atmospheres represent often 'targets of opportunity'
- State-of-the-art design (VIRHIS-EJSM) consists of:
  - Spatial resolution of 125 μrad/pixel
  - Spectral range: 0.4-1.9 μm (VIS) + 1.5-5.7 μm (IR)
  - Spectral resolution: 6 nm
Limb observations

- Limb scan observations offer several benefits for the study of the most tenuous parts of atmospheres
  - Long optical paths
  - Altitude scans at different tangent heights ($h_t$) provide insight on the vertical distribution of emitting species
  - Limited interference from surface emission/reflection
Spectro-imagers data

- Spectro-imagers data (hyperspectral cubes) consist of stacks of monochromatic images
- For each point of the image, a spectrum is also returned
- A 2-D characterization of emissions (e.g., lat. vs. altitude) become possible

VIRTIS- Rosetta limb scan above Martian atmosphere (Coradini et al., 2010)
Radiation Sources

- Suitable emission mechanisms for tenuous atmospheres:
  - ✗ Thermal emission
  - ✗ Scattering
  - ✔ Resonance fluorescence of sunlight
    - CO$_2$ @ 4.26 μm
  - ✔ De-excitation of species produced in excited states
    - OH @ 1.45 and 2.9 μm
Titan HCN as seen by Cassini-VIMS

- Adriani et al., 2011 mapped the 3 μm non-LTE emission by HCN
- Data can be compared directly against INMS data (Magee et al., 2009)
OH and O$_2$ emissions at Venus

- Piccioni et al. (2009) mapped the nighttime emissions of the two species involved in the oxygen cycle.
- OH emissions are of rotational nature and are potentially associated to a number of different reactions.
Callisto CO$_2$ atmosphere as seen by Galileo NIMS

- Carlson (1999) mapped the “characteristic airglow emissions produced by resonance scattering and fluorescence of solar radiation in the strong $v_3$ fundamental stretching band of CO$_2$ at 4.26 $\mu$m”

- “The number density at the surface is $n(0) \approx 4 \times 10^8$ cm$^{-3}$ and the vertical column abundance is $N = n(0) H \approx 8 \times 10^{14}$ cm$^{-2}$. At this low CO$_2$ abundance, and in the absence of other gases, the atmosphere would be nearly collisionless, constituting an exosphere. However, other gases may be present”
Focus on the Jupiter System

- Europa-Jupiter System Mission (ESA L-class, NASA Flagship-class) proposal is focused to the exploration of Galilean Satellites
- A major mission re-design is currently in progress
- Close flybys (<1000 km) of the three external galilean satellites remain major features of mission profile
- Great opportunity for joint exosphere science between INMS and IR spectroimagers
  - Different altitude ranges ⇒ complementary constraints to theoretical models
  - Highest spatial resolution achievable for IR spectroimagers in limb scans is about 250 m
Galilean moons

- Molecular Oxygen is considered the most important component of the atmospheres of Europa, Ganymede and likely Callisto. O emissions in UV are used as a proxy of $\text{O}_2$ (Yung & McElroy, 1977)

- Oxygen is produced by radiolysis and photolysis of water ice, but “the chemical pathways are not yet agreed upon” (Cassidy et al., 2010)

- Observations in UV and VIS suggests that sizeable amounts of $\text{O}_2$ and $\text{O}_3$ are trapped on the surface (Noll et al., 1996, Calvin & Spencer, 1997)

\begin{align*}
\text{hv} + \text{H}_2\text{O} & \rightarrow \text{OH} + \text{H} \\
\text{OH} + \text{OH} & \rightarrow \text{H}_2\text{O} + \text{O} \\
\text{O} + \text{OH} & \rightarrow \text{O}_2 + \text{H} \\
\text{O}_2 + \text{hv} & \rightarrow \text{O}{}^3\text{P} + \text{O}{}^3\text{P} \\
\text{O}_2 + \text{hv} & \rightarrow \text{O}{}^1\text{D} + \text{O}{}^3\text{P}
\end{align*}

Ganymede as seen by HST @ 1356 Å (McGrath et al., 2005)
Galilean moons: focus on oxygen

- $\text{O}_2 (a^1\Delta_g)$ is active in IR
  
  \[
  \begin{align*}
  \text{O}_2(a^1\Delta_g) & \rightarrow \text{O}_2(X^3\Sigma^-_g, v = 0) \quad 1.27 \ \mu\text{m} \\
  \text{O}_2(a^1\Delta_g) & \rightarrow \text{O}_2(X^3\Sigma^-_g, v = 1) \quad 1.58 \ \mu\text{m}
  \end{align*}
  \]

- $\text{O}_2 (a^1\Delta_g)$ is generated along several paths
  
  \[
  \begin{align*}
  \times \quad & \text{O}_3 + h\nu \ (175 - 310 \text{ nm}) \rightarrow O(1D) + O_2(a^1\Delta_g) \\
  \times \quad & O + O + M \rightarrow O_2(a^1\Delta_g) + M. \\
  \checkmark \quad & O_2(X^3\Sigma^-_g, v=0) \rightarrow O_2(b^1\Sigma^+_g, v=0) \\
  \checkmark \quad & O(1D) + O_2 \rightarrow O_2(b^1\Sigma^+_g) + O(3P), \quad \text{and} \quad O_2(b^1\Sigma^+_g) + O_2 \rightarrow O_2(a^1\Delta_g) + O_2.
  \end{align*}
  \]

OMEGA-Mars Express mapping of ozone on Mars (Altieri et al., 2009)
Galilean moons: focus on oxygen

- $O_2$ is also detectable by the Hertzberg II system
- On Earth and Venus (best studied systems) this emission is mostly related to $O(^3P)+O(^3P)+M \rightarrow O_2^*+M$
- Alternative patterns can not be ruled out

Venus nightglow as seen by VIRTIS-Venus Express
Garcia Munoz et al., 2011
Galilean moons: focus on oxygen

- **Atomic** oxygen can be also detected at 0.63 and 0.55 μm
  
  \[
  \text{O} + e^- \rightarrow \text{O}^1(P) + e^-
  \]
  
  \[
  \text{O}^3(P) \rightarrow \text{O}^1(D) + \text{hv} \, @ \, 6300 \, \text{Å}
  \]

- **OH** more challenging to produce along the Venus and Earth patterns
  
  \[
  \text{H} + \text{O}_3 \rightarrow \text{OH}^* + \text{O}_2
  \]
  
  \[
  \text{O} + \text{HO}_2 \rightarrow \text{OH}^* + \text{O}_2
  \]

Burger et al., 2011
Conclusions

- IR limb data can provide useful complementary information/boundary conditions to INMS in the characterization of tenuous atmospheres/exospheres.

- Hyperspectral data are particularly useful for their ability to provide a 2D spatial context to \textit{in situ} measurements.

- Improved radiometric performances of latest spectroimagers allowed the detection on very faint emissions, expected in conditions of tenuous atmospheres.

- Characterization of atmospheres of Galilean satellites in future Jupiter system missions could represent an opportunity for coordinated observations.
Galilean Satellites: alkalis

- Sodium D-lines (5889.95 and 5895.92 Å) falls in the range of VIS-IR spectroimagers
- Potassium (lines at 7664 and 7698 Å) could also be searched for