
Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, Belgium
The SOIR instrument

- **Venus Express (VEx) - ESA**
  - Launch in Baikonur in 2006
  - End in Dec. 2014

- **SOIR spectrometer**
  - Channel of SPICAV/SOIR on VEx
  - Echelle grating + AOTF
  - 2200 cm\(^{-1}\) to 4400 cm\(^{-1}\) (2.2 µm to 4.4 µm)
  - Divided in 94 diffracting orders
  - Order width: 20 to 37 cm\(^{-1}\)
  - Spectral resolution: 0.1 to 0.25 cm\(^{-1}\)

- **Measures 4 orders per second during an occultation**

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Detector optics and detector

Collimation and camera lens together in 1 parabolic mirror

AOTF

Echelle grating

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VEX

Order 171

Order 121

Order 149

Order 171

Order 121

Order 149

Transmitance vs. Wavenumber [cm\(^{-1}\)]

Venus 2016, Oxford, UK, 4-8 April (2016)
Slit position during an occultation
Measurement principles

- AOTF transfer function: sinc² like
  24 cm⁻¹ full width at mid height

- Mean free spectral range:
  19.5 cm⁻¹ (order 101) to 37.4 cm⁻¹ (order 194)

- AOTF transfer function shape determination is critical

- 7 diffraction orders have to be taken into account to correctly reconstruct measurement spectra

SOIR measurement modes

- SOIR can send 8 spectra per second to the Earth, at most 4 different AOTF frequencies per second
- → different binning cases

<table>
<thead>
<tr>
<th>Denomination (binning configuration)</th>
<th>Number of scanned orders</th>
<th>Number of lines in each bin</th>
<th>Number of binning groups</th>
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- 2 types of command
  - Hopping: selected AOTF frequencies are repeated on a 1s basis
  - Stepping: AOTF frequency is stepped by regular value

- When SOIR is turned on: Precooling for 600 s followed by the measurement

- Detector integration time varies between 1 ms and 150 ms

- Accumulations
  - Made to reduce the signal to noise
  - Vary between 1 and 23
  - Each accumulation is in fact the result of the difference between 2 successive recordings with AOTF ON and AOTF OFF
SOIR measurement modes

- Different types of measurement are available

- **Occultations:**
  - **Ingress** (hopping) – binning 12 or 16 (I) or binning 3 or 4 (I8)
  - **Egress** (hopping) – binning 12 or 16 (E) or binning 3 or 4 (E8)
  - Atmospheric **fullscan** (stepping) – any binning

- **Nadir** (N) – hopping

- **Calibration measurements:**
  - **Miniscan** (M) – stepping with small frequency steps – any binning
  - **Fullscan** (F) – stepping with large frequency steps corresponding to 1 order – any binning
  - **Other calibrations** (C)

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<tr>
<th>Measurement Type</th>
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<td>F</td>
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<td>Atmosphere fullscan</td>
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<td>Other calibration</td>
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</table>
SOIR PSA Level 2

- BROWSE, CALIB, CATALOG, DATA, DOCUMENT and INDEX directories

- DATA directory
  - Format YYYYMMDD_TNN
    - YYYY: year
    - MM: month
    - DD: day
    - T: type of measurement
    - NN: measurement number of the day
  - 2 x 2 files in each folder
    - OBS: measurement values
    - TC2: telecommand values file 2
SOIR PSA Level 2

- DATA directory
  - YYYYMMDD_TNN_OBS.TAB file contains measurement
    - 1 line per second
    - Fields:
      - Time
        - One field per scanned order
      - Observations
        - 320 values x 8 measurement (bins)
      - Housekeeping values
        - 16 fields: temperatures, voltages, etc.
PSA Level 2

- **BROWSE directory**
  - Each folder contains a JPG file
  - Sum of all the 320 pixels in each bin as a function of time
Treatments between Level 2 and Level 3

- Detector non-linearity correction
  - At low signal, non-linear response of the detector pixels

- Order determination
  - $f_{\text{AOTF}} \rightarrow$ wavenumber
  - Wavenumber compared to wavenumber centre of each diffraction order
  - Minimum value gives the diffraction order

- References
  - Nevejans et al., Compact high-resolution spaceborne echelle grating spectrometer with acousto-optical tunable filter based order sorting for the infrared domain from 2.2 to 4.3 µm, Applied Optics, Vol. 45, No. 21, 20 July 2006
  - Mahieux et al., In-flight performance and calibration of SPICAV SOIR onboard Venus Express, Applied Optics, Vol. 47, No. 13, 1 May 2008
  - Vandaele et al., Improved calibration of SOIR/Venus Express spectra, Optics Express, 21 (17), 21148 – 21161 (2013)
Transmittance calculation

- **Regression zone (S):**
  - 2 conditions: $z_{\text{Min}} > 220\text{km}$ & minimum of 20 points
  - If less than 20 points, decrease $z_{\text{Min}}$ BUT $z_{\text{Min}}$ must be $> z_{\text{unity}}$

- **Criteria check zone (W):**
  - Used to check the quality of the transmittance calculation

**Criteria**

1. $|1 - T(i)| < 2\delta T(i)$, $i \in W$
2. $\delta T(i) < \frac{1}{\text{snrmin}}$, $i \in W$
3. $\delta T(i) < \text{std}(T(\text{indsW}))$, $i \in W$
4. $T(i) - 1 < 2\delta T(i)$, $i \in V$
5. $|1 - T(R)| < 2\delta T(R)$

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Regions:

- **S**: Sun (regression)
- **W**: Criteria check
- **V**: Effective
- **T**: Transmittance
Transmittance calculation (details)

- Find indices, \( i_{\text{inds_T}} \), \( i_{\text{inds_U}} \), \( i_{\text{inds_W}} \)
- \( \text{altMin}=\text{altMin}-\text{stepMin} \)
  - if \( \text{indsS}=\text{minPoints} \)
    - if \( \text{altMin}=\text{altUnity} \)
      - stop
  - if \( \text{indsW}=\text{S} \)
    - Compute \( T, \Delta T, 5 \)-criteria
      - if \( \text{criterion}(i) < \text{threshold} \)
        - mean(\( \text{criterion}(i) < \text{threshold} \)) < \text{threshold} \)
          - Rejected: No level-0.8 produces for this set of spectra
          - Calculated data accepted
  - if \( \text{indsS}=\text{minPoints} \)
Altitude unity

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<th>Tangent altitudes (km)</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
<th>160</th>
<th>170</th>
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</thead>
</table>
Examples

Orbit 0219.1 Order 120 Bin 1

Orbit 0221.1 Order 121a Bin 1

Orbit 0398.1 Order 121a Bin 2

Best zone found for linear regression

Orbit 0793.1 Order 149 Bin 6

REJECTED

REJECTED
Treatments between Level 2 and Level 3

- Pixel to wavenumber calibration

- “Wrong” signal on pixels
  - Corrected by averaging by the two side pixels
  - Example: Orbit 130 (29/08/2006) Order 180 bin 2
PSA level 3

- BROWSE, CALIB, CATALOG, DATA, DOCUMENT and INDEX directories
- DATA directory
  - Format YYYYMMDD_TNN_OOO
    - YYYY: year
    - MM: month
    - DD: day
    - T: type of measurement
    - NN: measurement number of the day
    - OOO: diffraction order
  - 4 x 2 files in each folder
    - OOO: measurement values for order OOO
PSA level 3

- DATA directory
  - YYYYMMDD_TNN_OOO.TAB file contains measurement
    - One file per scanned order
    - If same order scanned twice file format becomes:
      - YYYYMMDD_TNN_OOOP.TAB
      - With P a letter
    - 1 line per spectrum
    - Fields:
      - Time
      - Bin
      - Binning
      - Measurement “Attitude”
      - AOTF frequency
      - Detector integration time
      - Pixel to wavenumber polynomial relation
      - Transmittance (320 values)
      - Noise (320 values)
      - Housekeeping values
        - 16 fields: temperatures, voltages, etc.
PSA Level 3

- CALIB directory
  - AOTF frequency to wavenumber (tuning curve)
    - Fields:
      - Type (pix $\rightarrow$ wn or wn$\rightarrow$ pix)
      - Binning
      - Bin
      - Relation (2$^{nd}$ order)
    - One for Nominal period and each Extension

- AOTF transfer function
  - Fields
    - Order, bin
    - Wavenumber (from -100 to 100 cm$^{-1}$, steps 0.1 cm$^{-1}$)
    - Values of TF bin (2001 values)
    - One bin / line
  - Only for bins 1 and 2 of binning 12
PSA Level 3

• CALIB directory
  o Blaze function
    ▪ Fields
      ➢ Order
      ➢ Wavenumber (from -100 to 100 cm\(^{-1}\), steps 0.1 cm\(^{-1}\))
      ➢ Values of BF (2001 values)
    ▪ Same for every binning

  o Resolution
    ▪ Fields
      ➢ Order
      ➢ Value of the resolution for each bin
Online Tool


**Access to SOIR measurements database**

- Access to Observation DataBase
  See [here](http://venus.aeronomie.be/en/soir/soir_database.htm) the the description of the Table contents.

- Access to SOIR Data Repository

- Access to SOIR Tools Repository

- **Link SOIR order number to spectral range and to retrieved molecule**: Table for converting the SOIR order number to wavenumber limits of the scanned interval and indicating molecules retrieved in each diffraction order.

**Science results navigation menu**

- What is a solar occultation - What can we learn from such observations?
- SOIR spectra
- Retrieval of atmospheric information
- A few of our results:
  - CO2
  - HCl
  - HF
  - CO
  - H2O and HDQ
  - Aerosols
- Retrieval of Atmospheric temperature and density
### Overview file

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<th>Distance to limb (120 km)[km]</th>
<th>Vertical resolution (120 km)[km]</th>
<th>Longitude planet (120 km)[deg]</th>
<th>Latitude planet (120 km)[deg]</th>
<th>Speed to Venus (120 km)[km/s]</th>
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Overview file: Search options
Access to Data

Repository of SOIR Data

ESA PSA : All CODMAC Level 2 (raw spectra) and CODMAC Level 3 (calibrated spectra) SOIR data are available via the PSA Data Center of ESA located at http://www.rssd.esa.int/psa. See here for a description of the PSA Data Center and how to access it. Data available (May 2012) cover the nominal mission and the Extended missions 1 to 3.

The description of the SOIR data levels and archiving structure can be found here.

Upon request, IASB-BIRA organizes specific workshops dedicated to understanding and using SOIR data.

CODMAC Level 5 Data (science) are available through the SOIR Data Repository of IASB-BIRA.

The SOIR data and tools are freely available upon respect of the Data Usage Policy. To gain access to the data, please register. This will be done automatically by trying to download one of the data/tools files. This will also allow us to send you warnings when new data or updates are made available on this page.

- **Batch1**
  Individual CO2 densities and temperature profiles used for the generation of the VAST profiles described in [Mahieux et al., 2012]. The zip file contains:
  - a file (Readme_SOIR.txt) describing the format of the data file and policy of data usage
  - a file (csvread_SOIR.m) containing a macro to import the data into Matlab
SOIR Wavenumber handle tool

- Tool to handle wavenumbers, pixels and orders in the SOIR data base

- Possibility to convert
  - Pixels to wavenumbers in a given order
  - Wavenumbers to pixels in a given order

- Possibility to anticipate where a line will be replicated due to the order addition

- Possibility to find out in which order a given wavenumber is measured
SOIR Data overview tool

- Tool to find an occultation in the SOIR database

- Possibility to search on
  - Order
  - Latitude
  - Longitude
  - Local solar time
  - Orbit number
  - Date

- Returns
  - List of occultations
  - Orbits information
  - Access to Plot occultation tool
  - Maps

- Only for occultations!
Plot occultation tool

- Tool to display
  - Spectra
  - Orbits characteristics
  - Housekeeping data

- PDS/PSA levels 2 and 3

- At start, asks for the repository location
  - needs adequate level 3 data repository

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<tr>
<td>1136-1583</td>
<td>Extension 2</td>
</tr>
<tr>
<td>1584-2451</td>
<td>Extension 3</td>
</tr>
<tr>
<td>2452-</td>
<td>Extension 4</td>
</tr>
</tbody>
</table>
Plot occultation tool - Level 2

Venus 2016, Oxford, UK, 4-8 April (2016)
Plot occultation tool - Level 3

- Select the measurements
  - Time in HHMMSS
  - Altitude in km

- 3D-plot of selected spectra

- 2D-plot of selected spectra

- Plot slit height in atmosphere

- Plot VEX speed

- Show scanned atmosphere

- Map geoposition: Longitude vs. latitude

Plot housekeeping data

- 16 choices
Plot occultation tool - Level 3

Venus 2016, Oxford, UK, 4-8 April (2016)
Higher level data

- We are preparing a complete dataset of all individual profiles and average ones
  - Density – Temperature profiles
  - Trace gases vertical profiles
  - VAST: binned latitudinal averages

- Will be reachable through the EuroPlanet VESPA interface
  [http://vespa.obspm.fr/planetary/data/epn/query/all/](http://vespa.obspm.fr/planetary/data/epn/query/all/)
Conclusions

• ‘New’ updated transmittances have been delivered to the PSA
• Re-analyse of the updated transmittances is on-going

• Still A LOT to do with this incredible data set
  o Improve the retrieval from the existing SOIR spectra
    ▪ Include the Detection Limits (OCS, etc)
    ▪ Correlation between the detected species (H₂O, SO₂) and aerosols
  o Perform comparison/synergy with other VEX datasets and/or with ground-based/HST observations
  o Validation wrt existing Venus atmosphere Models (GCM, 1-d RT)
Conclusions

• Do not hesitate to contact us:

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