Lightning on Venus

Searching for optical evidence with VIRTIS on Venus Express

Alejandro Cardesín Moinelo, ESAC
Antonio García Muñoz, ESTEC
G. Piccioni, IAPS-Rome

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Lightning in the Solar System

Lightning detected on Earth, Jupiter, Saturn, Uranus, Neptune

Practically, observed on most planetary atmospheres…

So we should expect it to occur on Venus, right?
Lightning on Venus
Electromagnetic Evidence

- Venera 11-14 (10-80 kHz),
  generated by the craft?
- PVO (0.1-30 kHz) @ 100 Hz (whistler modes?),
  correlation with topography?
- Galileo (0.1-5.7 MHz),
  too remote observation?
- Cassini flybys (0.125-16 MHz): no detection
  but detection at Earth
- VEx magnetometer: 'clear' evidence, terrestrial
  frequency, high dayside activity, whistler modes,…
  still controversial though...

IDSW 2013 Aranjuez
• Venera 9-10
• PVO Star Tracker broad band photometry
• Ground based observations: Hansell et al. 1995
• A. Garcia Muñoz at Calar Alto & La Palma
Lightning on Venus
What can we expect?

- Lightnings on Earth have the strongest emission lines at 777.3nm and 844.6nm, corresponding to atomic oxygen.
- Laboratory measurements at higher pressures predict that the dominant line at 777.3nm should be present on Venus.

However: lightning events are expected inside or below the cloud layer (<60km). May be hidden!
Lightning on Venus
What can we expect?

• **Transient Luminous Events (TLEs):** Sprites, Halos, Elves, are likely to appear at higher altitudes (50~90km)

• **Dominant emission around 280-420nm, peak at 337nm, (2nd positive band of N\textsubscript{2})** No presence of oxygen emissions
• **Huge data set**  
  (7 years of observations)

• **Full atmosphere coverage**  
  (all latitudes, longitudes, local times, …)

• **Multi-spectral information**  
  (UV, Visible and Near Infrared)

• **Images covering wide areas**  
  (Large FOV: 3.3 VIRTIS, 20 deg VMC)

• **”Enough” sensitivity**  
  (theoretically able to capture flashes)
VIRTIS - Visible Infra-Red Thermal Imaging Spectrometer

- **Instrument with two channels:**
  - **VIRTIS-M (Mapping):**
    - Visible 0.25-1µm
    - Infrared 1-5µm
    - 256 x 432 bands (δλ 1~10nm)
  - **VIRTIS-H (High Resolution):**
    - Infrared 2-5µm
    - 3452 bands (δλ ~1nm @ 3µm)

- **3-Dimensional data cubes**
  - 2 spatial dimensions (VIRTIS-M)
  - 1 spectral dimension

- **Scientific Objectives**
  - Global study of the atmosphere
  - Thermal mapping of the surface
  - Cloud Dynamics, Composition,...
  - But not designed for lightnings 😐

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Lightning & Transient Events on VIRTIS data

- Frame/Line scanner: not designed for lightning search.
- Transient events cause signal variation in a single frame/line.
- Effects can be filtered out by calibration, need to analyze raw data.

- Both Infrared and Visible data with same geometry.
- Visible signal from nightside atmosphere is almost negligible.

- We then use Visible Nightside Long Exposure Nadir Images.
Algorithm to search for signal:

• Of "a few" digital counts
• In "a few" bands
• Of "a few" pixels
• In a single line/frame

No assumption on emission bands. All wavelengths are considered.

We can detect transient events!

But we also detect all the spikes!
Future Work

• Optimize search algorithm / parameters
• Image pattern recognition
• Analysis of limb data
• Analysis of Infrared data
• Statistics of detection / non-detection

• Hopefully all this can be done with the help of a student trainee in 2014…
Questions?
Venus
Venus Atmosphere

- Carbon dioxide (96.5%)
- Nitrogen (3.5%)
- Argon (70 ppm)
- Sulfur dioxide (150 ppm)
- Neon (7 ppm)
- Helium (12 ppm)
- Carbon monoxide (17 ppm)
- Water vapor (20 ppm)
Venus Express

- **Launch 09 November 2005 04:43 UTC**
  - Venus Orbit Insertion 11th April 2006

- **Polar elliptical orbit**
  - Pericentre ~250 km
  - Apocentre ~66,000 km
  - Period ~24 hours

- **Scientific Objectives**
  - Atmosphere composition
  - Cloud morphology and structure
  - Atmosphere/surface interaction
  - Thermal mapping (and vulcanism)

- **Instrumentation**
  - VIRTIS (Imaging Spectrometer IR-VIS)
  - PFS (IR Spectrometer)
  - SPICAV (UV Spectrometer)
  - VMC (VIS-UV Camera)
  - ASPERA (Plasma science)
  - MAG (Magnetometer)
This part is not accessible by visible light neither for day time nor for night time!

We need the infrared light and only in night time!
Venus Atmosphere

- Sulfuric acid cloud layers
- Sulfuric acid haze
- Troposphere

Temperature (Celsius)

Bar
-200 -100 0 100 200 300 400 500

- Carbon dioxide (96.5%)
- Other (3.5%)
- Nitrogen (0.35%)
- Sulfur dioxide (150 ppm)
- Argon (70 ppm)
- Neon (7 ppm)
- Helium (12 ppm)
- Carbon monoxide (17 ppm)
- Water vapor (20 ppm)

Polar collars
Hadley cell
Oxygen airglow

Day to night circulation in the thermosphere
Polar vortexes
Data Calibration pipeline - Summary

PDS RAW data cubes

Calibration Pipeline

- Dark Frame removal
- Bad/Saturated pixels

Pre Processing

- Thermal correction
- Bad frame recovery

Radio metric Spectral

- Spectral Registration
- Radiometric Calibration

Post Processing

- Despiking
- Destriping

IEEE Proceedings: WHISPERS Conference 2009

IEEE Transactions: Special Issue on Hyperspectral Image Processing 2009

\[ \text{Rad}(b,s,l)_{IR} = \frac{\text{DN}(b,s,l)_{IR}}{t_{IR} \cdot R(b,s)_{IR}} \]
SPACE OPS 2010

VIRTIS Observation Coverage Maps

Frew et al.
Thermal Brightness @ 5um
Thermal brightness measured distributed along local time
Exposure Time < 2s
Orbits 0-880

A. Cardesin Moinelo, G. Piccioni
AGU Fall Meeting – JGR 2009

CO2 Non-LTE Emission @ ~4.3um
Not corrected for emission angle
Not corrected for flat field
Emission Angle < 90°
Exposure time < 2s
Orbits 0-500

Oxygen Airglow @ ~1.27um
Corrected for emission angle
and for thermal contribution
Exposure time > 0.1s
Orbits 0-883

R. Hueso et al
Current Study on Non Local Thermo-Dynamical Equilibrium

CO2 Non-LTE Emission @ ~4.3µm
Not corrected for emission angle
Not corrected for flat field
Emission Angle < 80°
Exposure time < 2s
Orbits 23-920

A. Cardesin et al.
General VIRTIS Observation Strategy for Nadir or off-Nadir

Case 1, Pericenter observation

Case 2, Off-Pericenter observation

Case 3, Apocenter observation
The vortex extends 2700 x 890 km

The vortex shape varies rapidly with time
A new view of the polar vortex: tripole !!!

START_TIME = 2008-01-18T17:12:13.719
STOP_TIME = 2008-01-18T17:24:35.740

5.2 microns
(65 km)
VIRTIS Instrument
# VIRTIS details

<table>
<thead>
<tr>
<th></th>
<th>VIRTIS-M Visible</th>
<th>VIRTIS-M Infrared</th>
<th>VIRTIS-H</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spectral range (nm)</strong></td>
<td>280 – 1100</td>
<td>1050 – 5130</td>
<td>1840 – 4990</td>
</tr>
<tr>
<td><strong>Spectral resolution λ/Δλ</strong></td>
<td>150 – 500</td>
<td>100 – 500</td>
<td>1300 – 3000</td>
</tr>
<tr>
<td><strong>Spectral sampling (nm) [note 1]</strong></td>
<td>1.89</td>
<td>9.47</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Field of view (mrad x mrad)</strong></td>
<td>64 (slit) x 64 (scan)</td>
<td></td>
<td>0.44 x 1.34</td>
</tr>
<tr>
<td><strong>Max spatial resolution (μrad)</strong></td>
<td>250 (slit) x 250 (scan)</td>
<td></td>
<td>–</td>
</tr>
<tr>
<td><strong>Image size, full FOV high resolution (pixels)</strong></td>
<td>256 x 256</td>
<td></td>
<td>–</td>
</tr>
<tr>
<td><strong>noise equivalent spectral radiance</strong></td>
<td>1.4 x 10⁻²</td>
<td>1.2 x 10⁻⁴</td>
<td>1.2 x 10⁻⁴</td>
</tr>
<tr>
<td><strong>(central band, Wm⁻²sr⁻¹μm⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Telescope</strong></th>
<th>Shafer Telescope</th>
<th>Shafer Telescope</th>
<th>off-axis parabolic mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pupil diameter (mm)</strong></td>
<td>47.5</td>
<td></td>
<td>32</td>
</tr>
<tr>
<td><strong>Imaging F#</strong></td>
<td>5.6</td>
<td>3.2</td>
<td>2.04</td>
</tr>
<tr>
<td><strong>Etendue (m² sr)</strong></td>
<td>4.6 x 10⁻¹¹</td>
<td>7.5 x 10⁻¹¹</td>
<td>0.8 x 10⁻⁹</td>
</tr>
<tr>
<td><strong>Slit dimension (mm)</strong></td>
<td>0.038 x 9.53</td>
<td></td>
<td>0.029 x 0.089</td>
</tr>
<tr>
<td><strong>Spectrometer</strong></td>
<td>Offner Relay</td>
<td>Offner Relay</td>
<td>Echelle spectrometer</td>
</tr>
<tr>
<td><strong>Detectors</strong></td>
<td>Thomson TH7896 CCD</td>
<td>HgCdTe [note 2]</td>
<td>HgCdTe [note 2]</td>
</tr>
<tr>
<td><strong>Sensitivity area format</strong></td>
<td>508 x 1024</td>
<td>270 x 436</td>
<td>270 x 436</td>
</tr>
<tr>
<td><strong>Pixel pitch (mm)</strong></td>
<td>19</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td><strong>Operating temperature (K)</strong></td>
<td>150 – 190</td>
<td>65 – 90</td>
<td>65 – 90</td>
</tr>
<tr>
<td><strong>Spectral range (μm)</strong></td>
<td>0.25 – 1.05</td>
<td>0.95 – 5.0</td>
<td>0.95 – 5.0</td>
</tr>
<tr>
<td><strong>Mean dark current</strong></td>
<td>&lt; 1 e/s</td>
<td>&lt; 2 fA @ 90K</td>
<td>&lt; 2 fA @ 90K</td>
</tr>
</tbody>
</table>

Notes. 1: depends on selected mode of operation; the maximum value is shown. 2: VIRTIS-M and VIRTIS-H use identical IR detectors.
Venus Express Spacecraft