Study of Venus’ cloud layers by polarimetry with SPICAV/VEx

Loïc Rossi 1, Emmanuel Marcq 1, Franck Montmessin 2, Jean-Loup Bertaux 2, Anna Fedorova 3 4, Oleg Korabel’v 3 4, Daphne Stam 5

1 LATMOS/UVSQ, Guyancourt, France
2 LATMOS/CNRS, Guyancourt, France
3 Space Research Institute/IKI, Russia
4 Moscow Institute of Physics and Technology, Dolgoprudny, Russia
5 Technische Universiteit Delft, Delft, The Netherlands

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Polarization studies of Venus

Ground-based observations 1920s-1970s (Lyot, Coffeen, Dollfus…)

- Hansen and Hovenier (1974) used a polarized radiative transfer code to retrieve the parameters of the cloud layers
- Pioneer Venus OCPP: polarimetric measurements analyzed by Kawabata (1980), Sato (1996) to retrieve parameters of the haze layer

Main results

<table>
<thead>
<tr>
<th>Shape</th>
<th>spherical droplets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazes</td>
<td>$r_h \sim 0.25 , \mu m$ $\nu_h \sim 0.25$</td>
</tr>
<tr>
<td>Cloud</td>
<td>$r_c \sim 1 , \mu m$ $\nu_c \sim 0.07$</td>
</tr>
<tr>
<td>Composition</td>
<td>concentrated $\text{H}_2\text{SO}_4 - \text{H}_2\text{O}$ solution</td>
</tr>
</tbody>
</table>
SPICAV-IR observations

Principle of measurement

SPICAV-IR is an infrared spectrometer onboard ESA’s Venus Express spacecraft, working in the 0.65 – 1.7 µm range.

- spectral window and continuum measurement
- based on an acousto-optic tunable filter (AOTF)
- produces two beams polarized in perpendicular directions

Degree of linear polarization

\[ P_\ell = \frac{P_\perp - P_\parallel}{P_\perp + P_\parallel} = \frac{d_1 - d_0}{d_1 + d_0} \]
Linear polarization degree map for $\lambda = 1.274\mu m$
Linear polarization degree map for $\lambda = 1.324 \mu m$
Figure: Linear polarization degree at $\lambda = 1.324\,\mu m$
Polarization patterns produced by Mie scattering on spherical particles depends on the size parameter $x = \frac{2\pi r}{\lambda}$.

- $x \ll 1$: Rayleigh-like scattering, positive polarization
- $x > 1$: Mie regime, complex features, in particular the polarimetric glory

Estimates for cloud particles
- spherical particles
- $r \sim 1 \, \mu m$
- $n_r \sim 1.42$ at $\lambda = 1 \, \mu m$
Polarization patterns produced by Mie scattering on spherical particles depends on the size parameter \( x = \frac{2\pi r}{\lambda} \).

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**Estimates for cloud particles**
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- \( r \sim 1 \, \mu m \)
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Mie scattering

Polarization patterns produced by Mie scattering on spherical particles depends on the size parameter 
\[ x = \frac{2\pi r}{\lambda}. \]

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Estimates for cloud particles

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- \( n_r \sim 1.42 \) at \( \lambda = 1 \, \mu m \)
Cloud modeling

Cloud layers

- Polarized, multiple scattering radiative transfer model based on the doubling-adding method, provided by D. Stam
- Clouds described by two layers, each homogeneously mixed

- Observations of glories will yield values for the cloud layer
- Observations at higher phase angles will provide information about hazes

<table>
<thead>
<tr>
<th>Clouds parameters</th>
<th>$r_{\text{eff}}$</th>
<th>$\nu_{\text{eff}}$</th>
<th>$n_r$</th>
<th>$\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haze layer</td>
<td>0.25</td>
<td>0.25</td>
<td>$n$</td>
<td>$\tau_h$</td>
</tr>
<tr>
<td>Cloud layer</td>
<td>$r_c$</td>
<td>0.07</td>
<td>$n$</td>
<td>30</td>
</tr>
</tbody>
</table>
Cloud modeling

Modeling at $\lambda = 1.1 \ \mu m$

Parameters retrieval

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Main effect on degree of polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_r$</td>
<td></td>
</tr>
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</table>

Dependence of model to $n_r$

$r_{eff} = 1.05$, $\nu_{eff} = 0.07$, $\tau_h = 0.$

$n_r = 1.41$

$n_r = 1.42$

$n_r = 1.43$
Cloud modeling

Modeling at $\lambda = 1.1 \mu m$

Parameters retrieval

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<td>$n_r$</td>
<td>degree of polarization</td>
</tr>
<tr>
<td>$r_{\text{eff}}$</td>
<td>position of glory minimum</td>
</tr>
</tbody>
</table>

Dependence of model to $r_{\text{eff}}$

$n_r = 1.42$, $\nu_{\text{eff}} = 0.07$, $\tau_h = 0$. $r_{\text{eff}} = 1.0 \mu m$, $r_{\text{eff}} = 1.1 \mu m$, $r_{\text{eff}} = 1.2 \mu m$
Cloud modeling

Modeling at $\lambda = 1.1 \, \mu m$

Parameters retrieval

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<tr>
<td>$r_{\text{eff}}$</td>
<td>position of glory</td>
</tr>
<tr>
<td>$\nu_{\text{eff}}$</td>
<td>minimum shape of glory</td>
</tr>
</tbody>
</table>

Dependence of model to $\nu_{\text{eff}}$

$n_r = 1.42$, $r_{\text{eff}} = 1.05$, $\tau_h = 0.$

- $\nu_{\text{eff}} = 0.05$
- $\nu_{\text{eff}} = 0.07$
- $\nu_{\text{eff}} = 0.09$
Cloud modeling

Modeling at $\lambda = 1.1 \ \mu m$

Parameters retrieval

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<td>$\nu_{\text{eff}}$</td>
<td>shape of glory</td>
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<tr>
<td>$\tau_h$</td>
<td>positive polarization</td>
</tr>
</tbody>
</table>

Dependence of model to $\tau_h$

$n_r = 1.42$, $r_{\text{eff}} = 1.05$, $\nu_{\text{eff}} = 0.07$

L. Rossi  Polariometric study of Venus’ clouds
Low latitudes

Orbit 1463-7 @ 1.101\,\mu m, r_{eff}=1.05, \nu_{eff}=0.12, \tau_h = 0.03

Linear polarization degree (%) vs. Phase angle (°)

- $n_r = 1.424$
- $n_r = 1.422$
- $n_r = 1.420$
- orbit 1463-7
Low latitudes

Orbit 1463-7 @ 1.274\,\mu m, r_{eff}=1.05, \nu_{eff}=0.12, \tau_{h}=0.03

$L.\,Rossi$  \hspace{1cm} Polarimetric study of Venus' clouds
Low latitudes

Orbit 1478-8 @ 1.101µm, $r_{\text{eff}} = 1.2$, $\nu_{\text{eff}} = 0.07$, $\tau_h = 0.05$

- $n_r = 1.42$
- $n_r = 1.418$
- $n_r = 1.415$

Linear polarization degree (%) vs. Phase angle (°) for orbit 1478-8.
Low latitudes

Orbit 1478-8 @ 1.274µm, $r_{\text{eff}} = 1.2$, $\nu_{\text{eff}} = 0.07$, $\tau_h = 0.05$

- $n_r = 1.418$
- $n_r = 1.415$
- $n_r = 1.412$

orbit 1478-8
At high latitudes, a strong positive polarization is observed. Stronger influence of hazes required to match observations. Optical depth vary from $\sim 0.3$ to $\sim 0.7$. Upper limit for $\tau_h$ can reach 0.17 at very high latitudes.
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Conclusions

SPICAV-IR polarization data is in good agreement with previous observations, in particular with OCPP.

Polarization maps confirm values of $r_{\text{eff}} \sim 1$ µm, with narrow size distribution for cloud particles at a planetary scale.

We always observe the glory at low phase angles, as VMC in photometry: particles are spherical.

Retrieved refractive indices are compatible with sulfuric acid solution.

The haze optical thickness increases towards the poles.

Perspectives

- Parameters retrieval for each orbit.
- Investigate latitudinal, temporal variability (local time and long term).
## Acknowledgments

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loic.rossi@latmos.ipsl.fr