

# Study of Venus cloud layers by polarimetry using SPICAV/VEx

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## 1. CONTEXT

- Since 1929, polarization has been used to characterize Venus' clouds and hazes refractive index, radius and particle size distribution;
- Most of our knowledge is based on measurements and modeling made by Lyot[4], Hansen and Hovenier[1], Kawabata[2] and Sato[5] with ground and space observation;
- Our goal here is to make new measurements using the polarimetric data provided by the instrument SPICAV-IR on Venus Express, in orbit since 2006.

	Main cloud layer	Hazes
Altitude	50 to 75 km	30 to 90 km
Composition	H <sub>2</sub> SO <sub>4</sub> -H <sub>2</sub> O	H <sub>2</sub> SO <sub>4</sub> -H <sub>2</sub> O
Radius	$r \sim 1 \mu\text{m}$	$r \sim 0.25 \mu\text{m}$

Table: Current knowledge of Venus clouds.

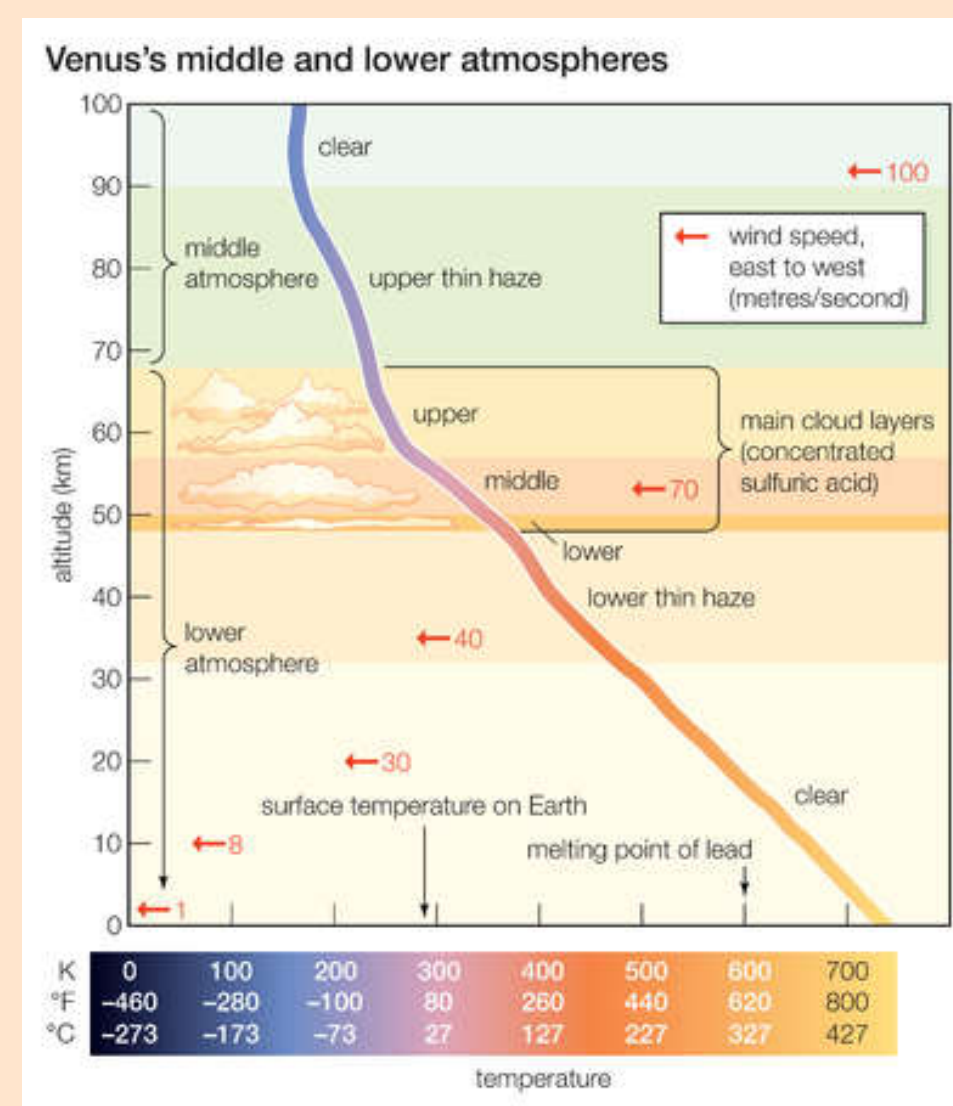


Figure: Structure of Venus clouds

## 2. SPICAV-IR

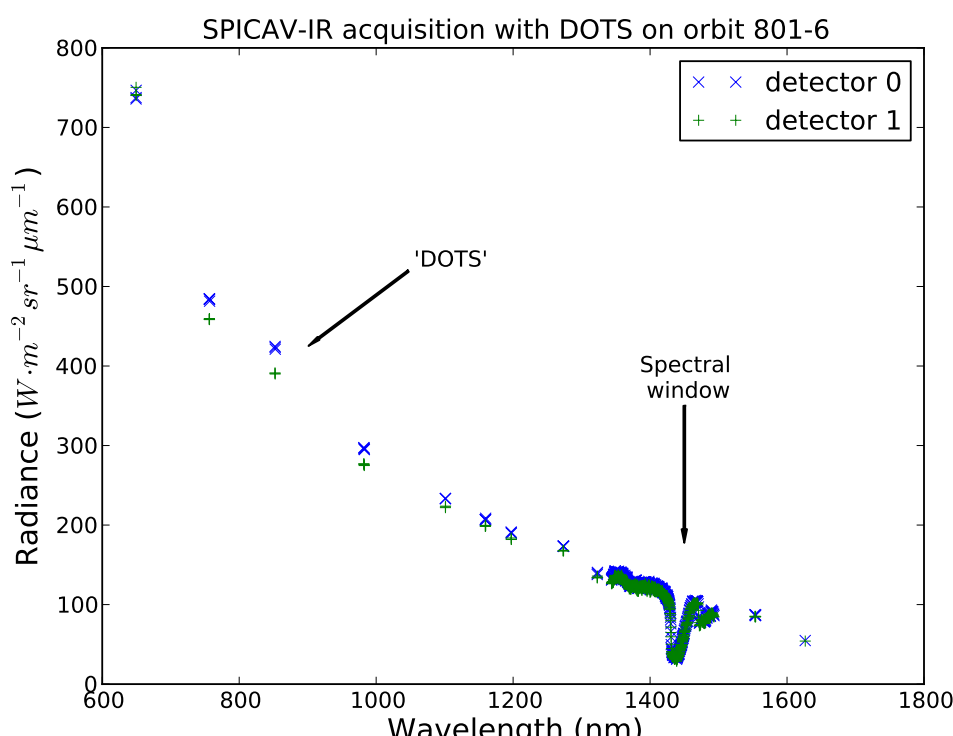


Figure: Example of SPICAV acquisition.

Channel	Coverage
SW	0.65 μm—1.05 μm
LW	1.05 μm—1.7 μm

Table: SPICAV characteristics

SPICAV-IR is a spectrometer on-board the Venus Express spacecraft[3]. Based on an Acousto-Optical Tunable Filter (AOTF), it produces two beams linearly polarized in perpendicular directions.

Measure of the degree of linear polarization:

$$P_{\ell} = \frac{P_{\perp} - P_{\parallel}}{P_{\perp} + P_{\parallel}} = \frac{d_1 - d_0}{d_1 + d_0}$$

Cross-calibration can be performed by knowing that for any wavelength  $P_{\ell} = 0$  at zero degree of phase angle. Acquisition is made with spectral windows and sets of 3, 5 or 10 points for continuum measurement. We use the latter points to measure polarization in up to 14 wavelengths.

## 5. CLOUD MODEL

- The cloud model has a layer of haze above a cloud layer, each homogeneously mixed;
- Polarization retrieved with the doubling-adding method;
- Angular position and shape of the glory dependent on the cloud parameters: **the glory is a tool to characterize the cloud layer**;
- Thickening hazes increases the polarization degree near 90° of phase angle: **possible measurement of  $\tau_h$  at higher phase angles**.

	$r_{\text{eff}}$	$\nu_{\text{eff}}$	$n_r$	$\tau$
Haze layer	0.25	0.25	$n$	$\tau_h$
Cloud layer	$r_c$	0.07	$n$	30

Table: Parameters of the cloud model

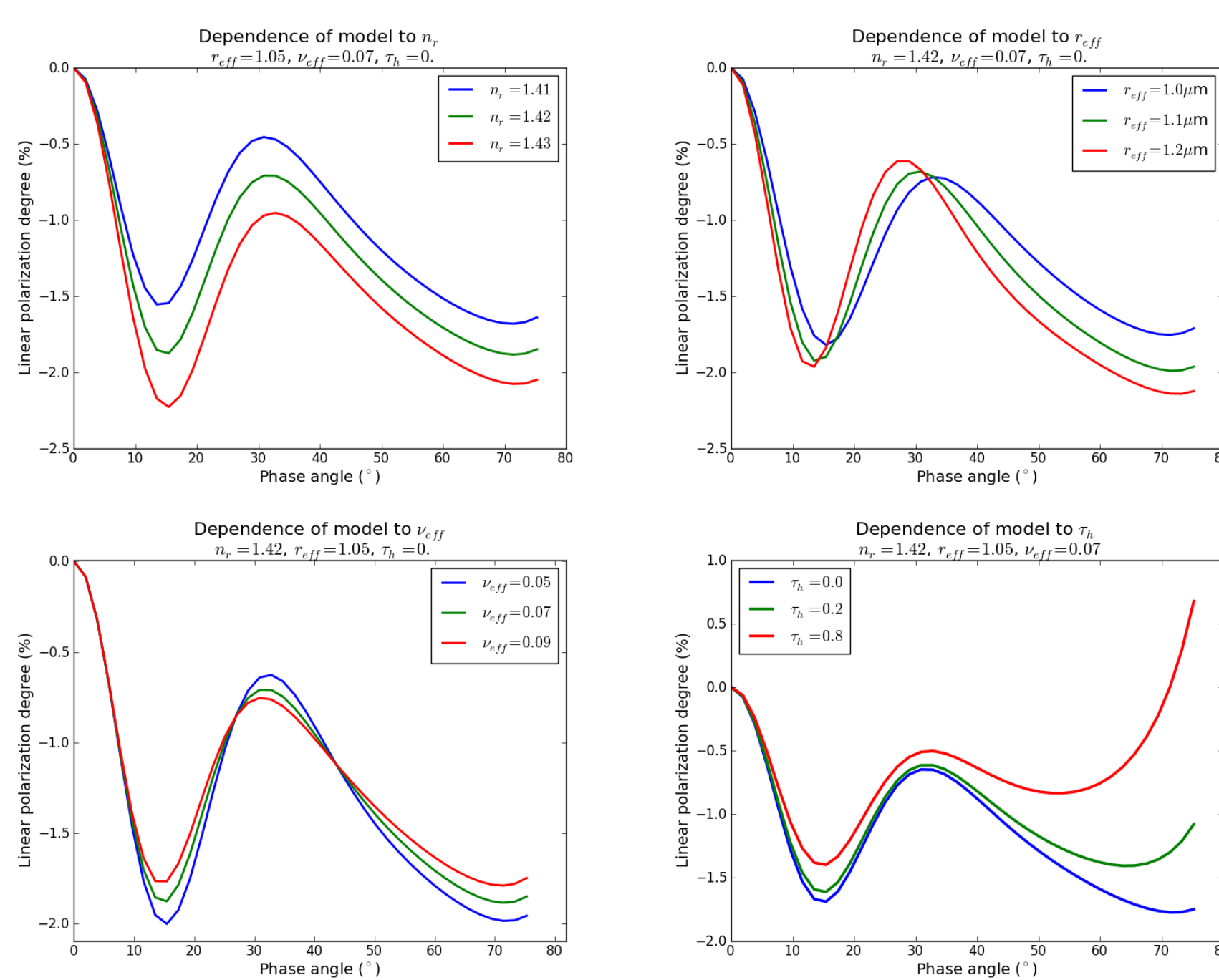


Figure: Illustration of the influence of the cloud parameters  $n_r$ ,  $r_{\text{eff}}$ ,  $\nu_{\text{eff}}$ , and  $\tau_h$  on the model.

## 3. SPICAV OBSERVATIONS

- Observations performed in nadir and spot-tracking mode;
- VEx has a north polar orbit: observations mostly located in northern hemisphere;

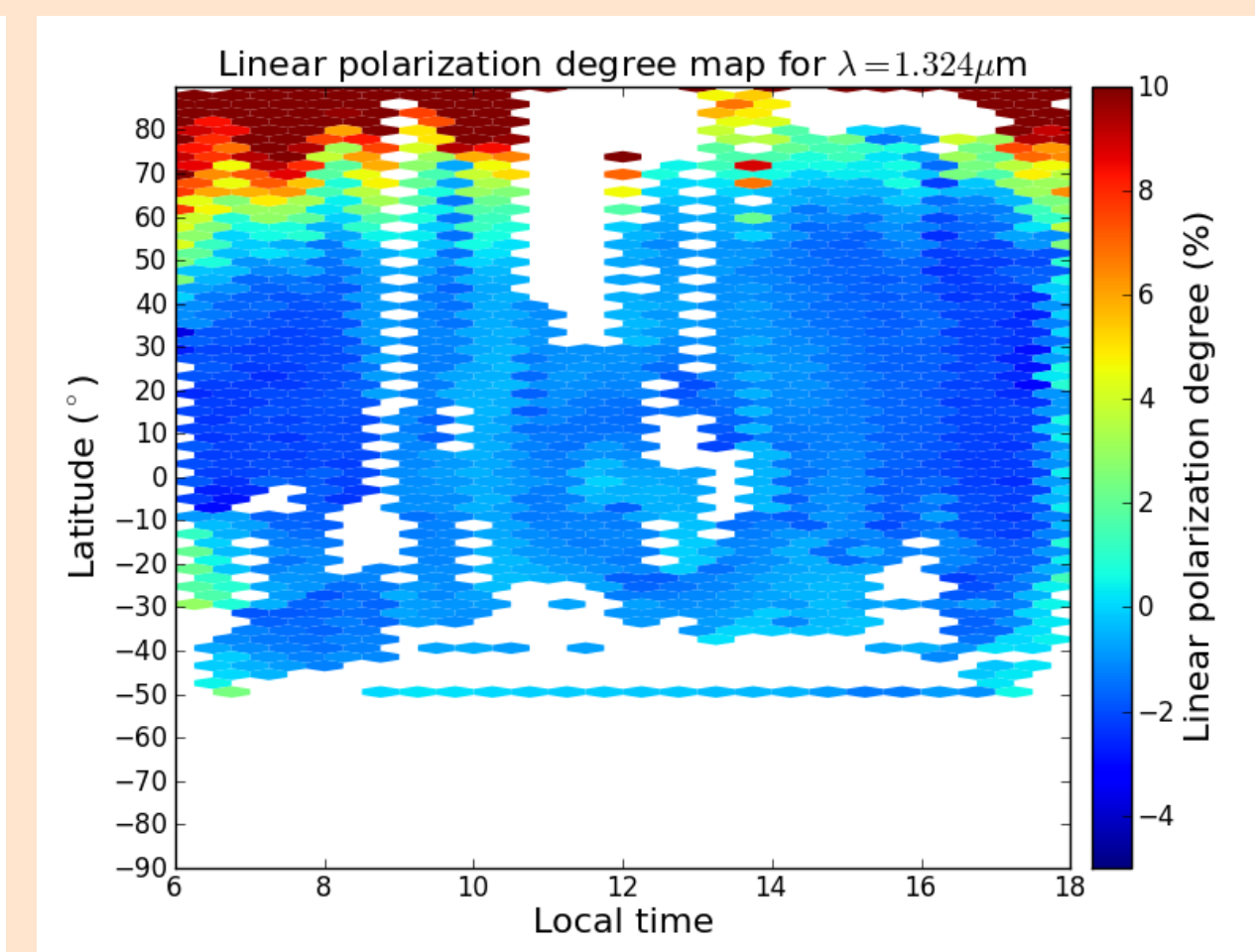
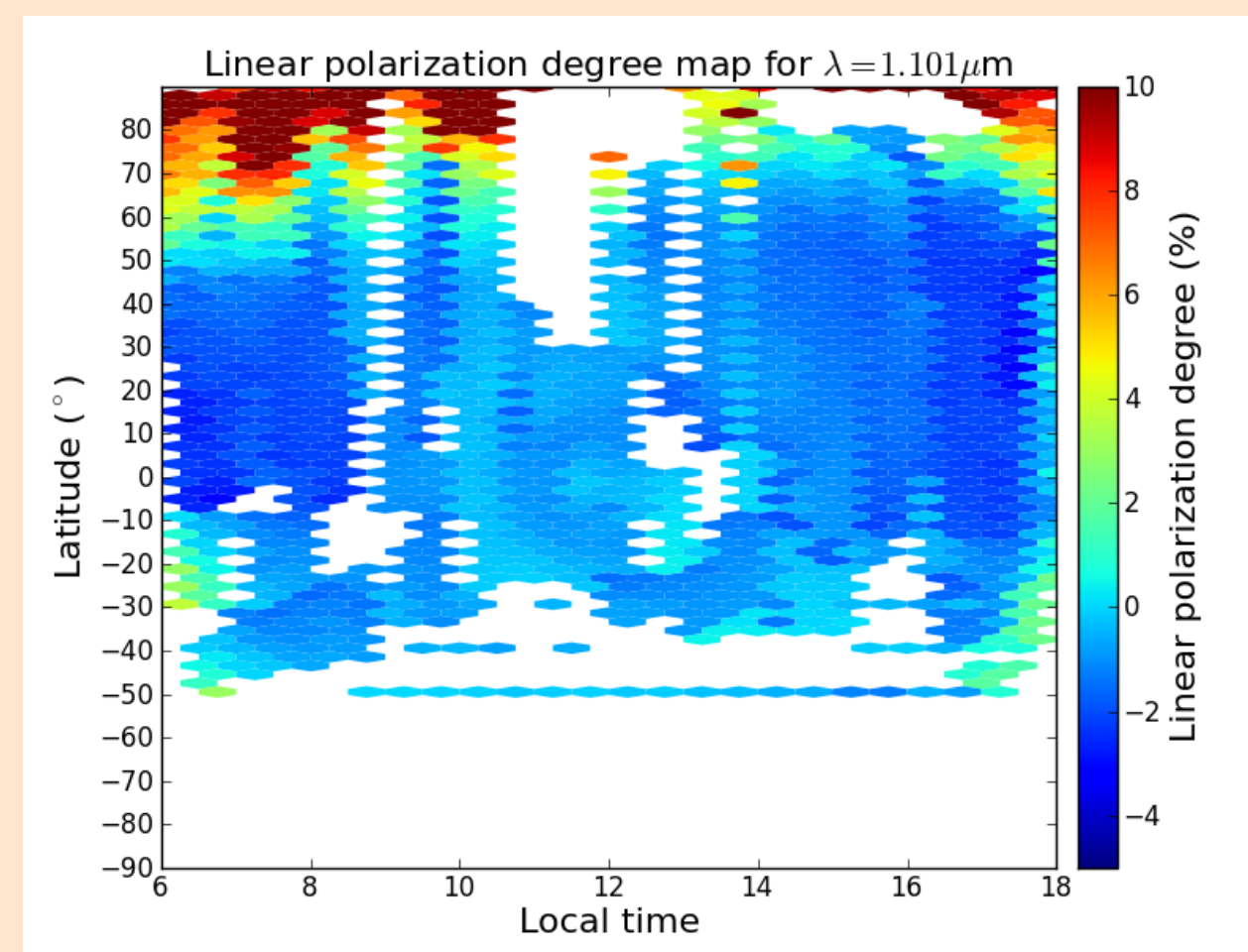


Figure: Average maps from SPICAV polarization observations at 1101 nm and 1553 nm for all orbits from May 2006 to May 2010.

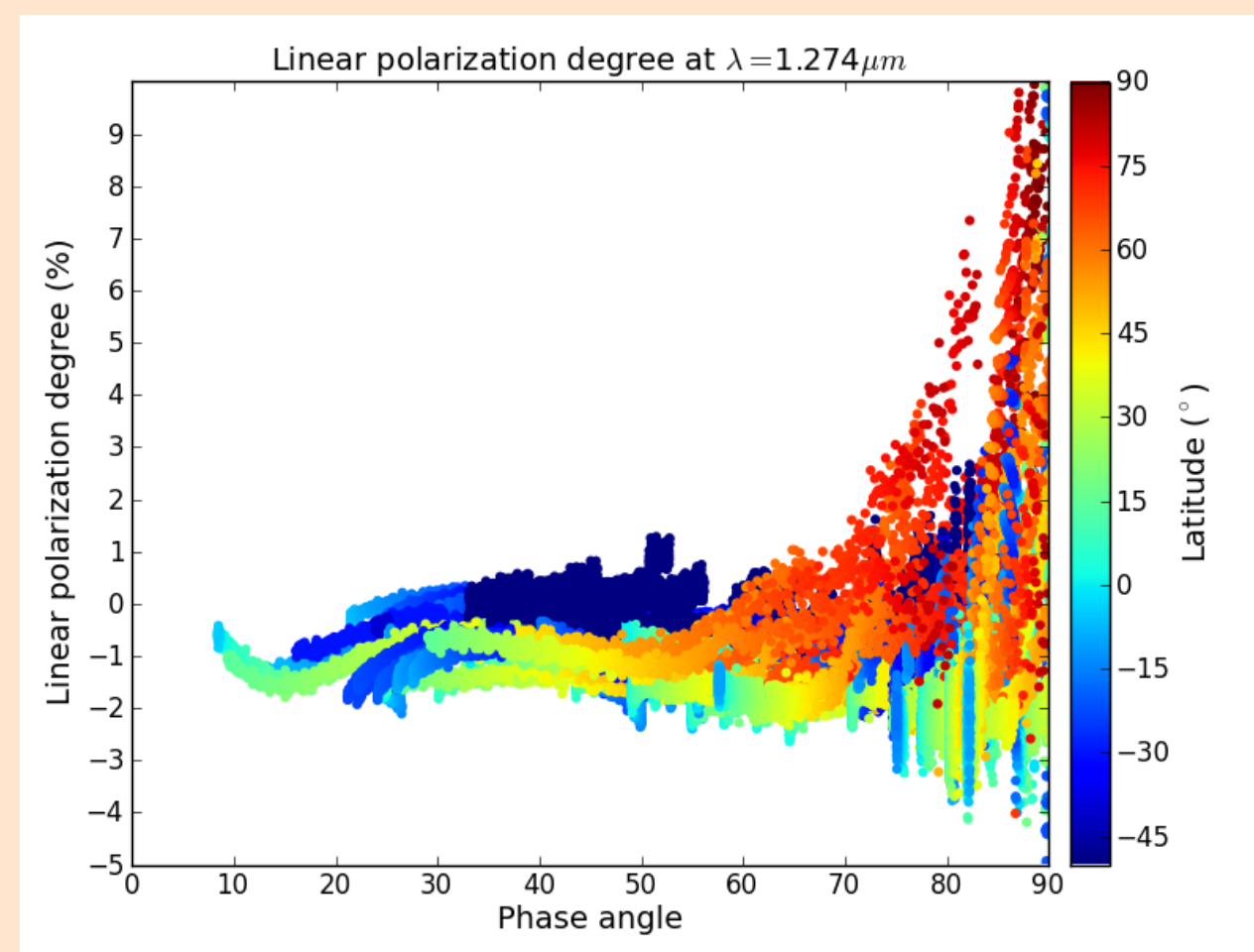


Figure: Polarization nadir observations at  $\lambda = 1.274 \mu\text{m}$  from May 2007 to May 2010 as a function of phase angle and latitude. The glory is visible at  $\sim 15^\circ$  of phase angle.

Polarization is quite uniform across the planet with the exception of the high latitudes:

- At low latitudes, the polarization is mostly negative;
- At higher latitudes it becomes positive, reaching values up to +10%;
- An average glory-related feature is visible around the subsolar point, showing that **a glory is visible nearly every time SPICAV-IR observes at low latitudes**;
- The glory is **also observed in photometry** by the Venus Monitoring Camera (VMC) onboard Venus Express.

## 4. LORENZ-MIE THEORY

Two scattering regimes can be distinguished with respect to the size parameter  $x = \frac{2\pi r}{\lambda}$ .

- Rayleigh regime** ( $x \lesssim 1$ ):

Degree of linear polarization always positive peaking at +100% for  $\alpha = 90^\circ$

- Mie regime** ( $x \gtrsim 1$ ):

Generates optical phenomena such as the **glory**: a strong negative polarization feature at phase angles  $< 20^\circ$ . Particle size distribution described by  $r_{\text{eff}}$ , effective radius and  $\nu_{\text{eff}}$  variance of the size distribution.

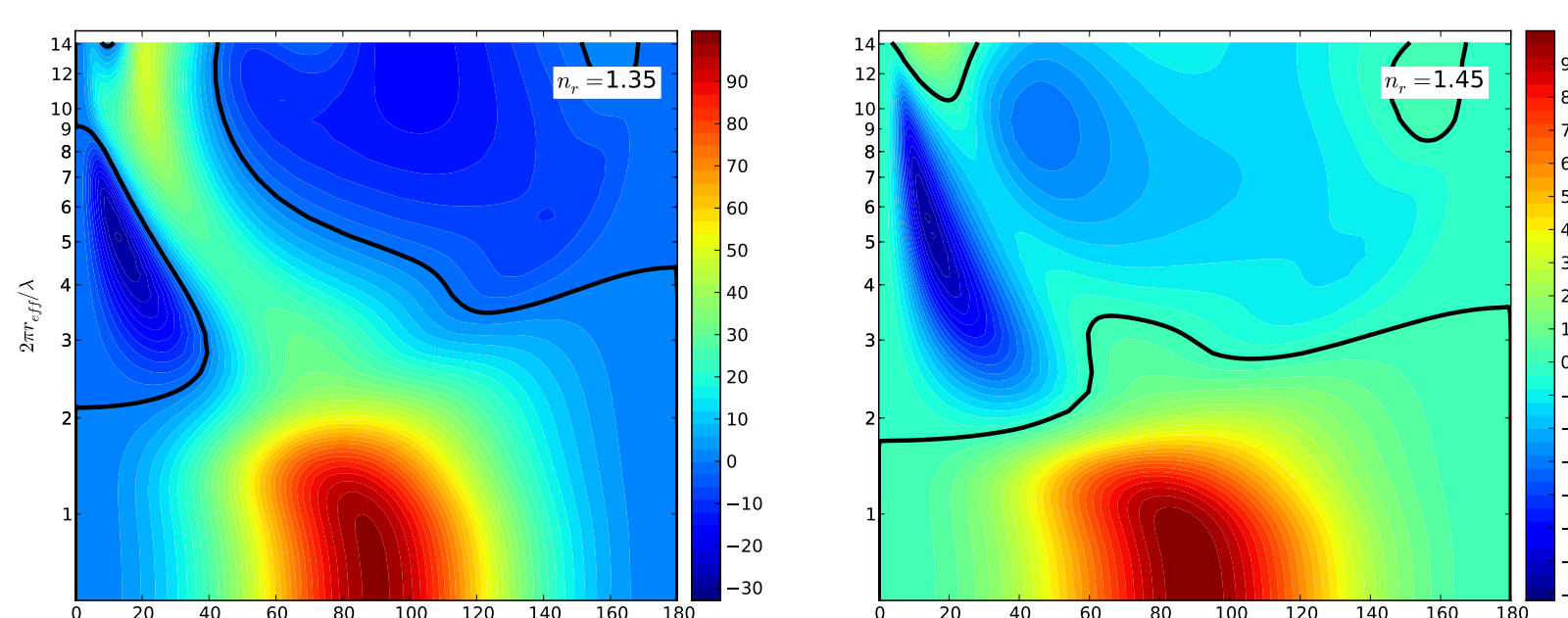


Figure: Degree of linear polarization as a function of phase angle and size parameter for unpolarized light scattered by spherical droplets with  $n_r = 1.35$  and 1.45.

Single scattering gives estimates of the cloud parameters:

- SPICAV observations **consistent with  $r \sim 1 \mu\text{m}$  spherical droplets with  $n_r \sim 1.42$  at  $\lambda = 1 \mu\text{m}$**
- Positive polarization observed at  $\lambda = 1 \mu\text{m}$ ; created by **submicrometric particles**.

## 6. GLORY ANALYSIS

Model applied to some glories yields values of the cloud parameters at low latitude.

- Refractive indices of  $n_r \sim 1.42$  at  $\lambda = 1.1 \mu\text{m}$ , **compatible with concentrated H<sub>2</sub>SO<sub>4</sub> solution**;
- Particle effective radii  $r_{\text{eff}} \sim 1.1 \mu\text{m}$ ;
- Small variance of the size distribution:  $\nu_{\text{eff}} \sim 0.07$ ;
- Haze optical thickness  $\tau_h \sim 0.05$  at lower latitudes (at  $\lambda = 1.1 \mu\text{m}$ ).

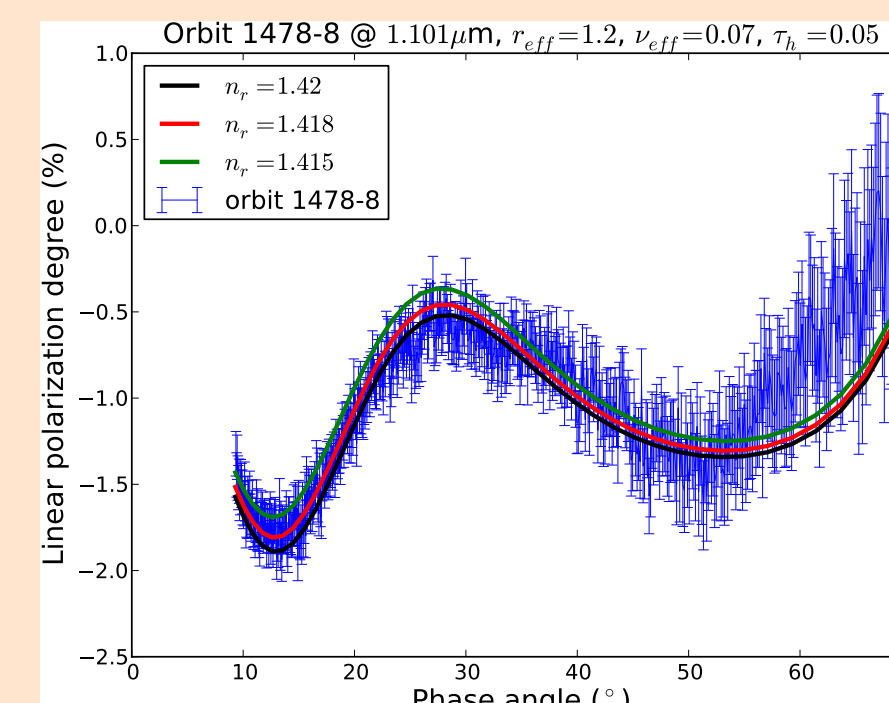


Figure: Polarization glory from orbit 1478-8 at  $1.101 \mu\text{m}$  with best model with  $n_r = 1.418$ ,  $r_{\text{eff}} = 1.2 \mu\text{m}$ ,  $\nu_{\text{eff}} = 0.07$ ,  $\tau_h = 0.05$  at all latitudes.

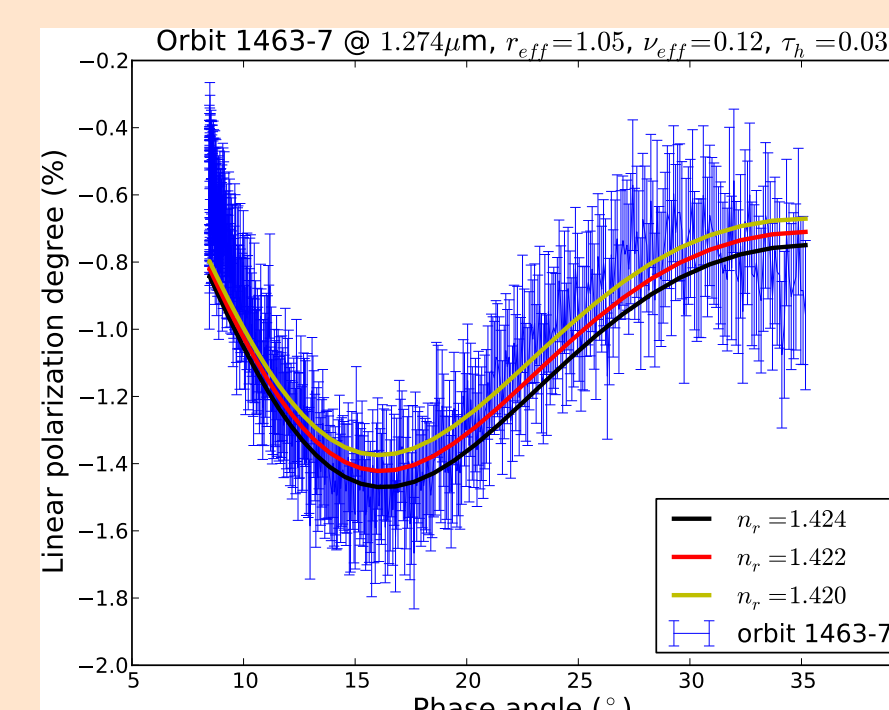


Figure: Polarization glory from orbit 1463-7 at  $1.274 \mu\text{m}$  with best model with  $n_r = 1.422$ ,  $r_{\text{eff}} = 1.05 \mu\text{m}$ ,  $\nu_{\text{eff}} = 0.12$ ,  $\tau_h = 0.03$  at all latitudes.

## 7. HIGHER LATITUDES

At higher latitudes, thicker haze is required to match observed polarization.

- Because of nadir observation, different phase angles correspond to different latitudes;
- Different models are required at higher phase angles;
- The properties of the clouds change with latitude, with increasing haze optical thickness with increasing latitude.**

From observations between orbits 400 and 1500 we can put an **upper limit on the haze optical thickness at high latitude with  $\tau_h = 0.17$  at  $\lambda = 1.1 \mu\text{m}$ .**

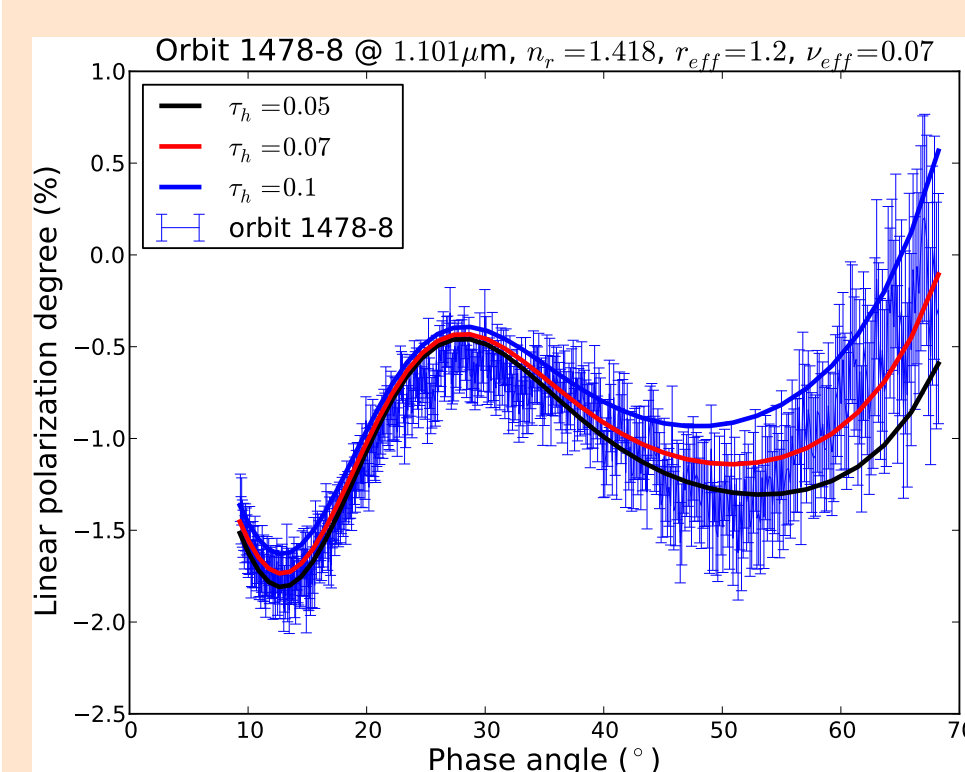


Figure: Polarization glory from orbit 1478-8 at  $1.101 \mu\text{m}$  with model  $n_r = 1.418$ ,  $r_{\text{eff}} = 1.2 \mu\text{m}$ ,  $\nu_{\text{eff}} = 0.07$ , for different values for  $\tau_{\text{eff}}$ .

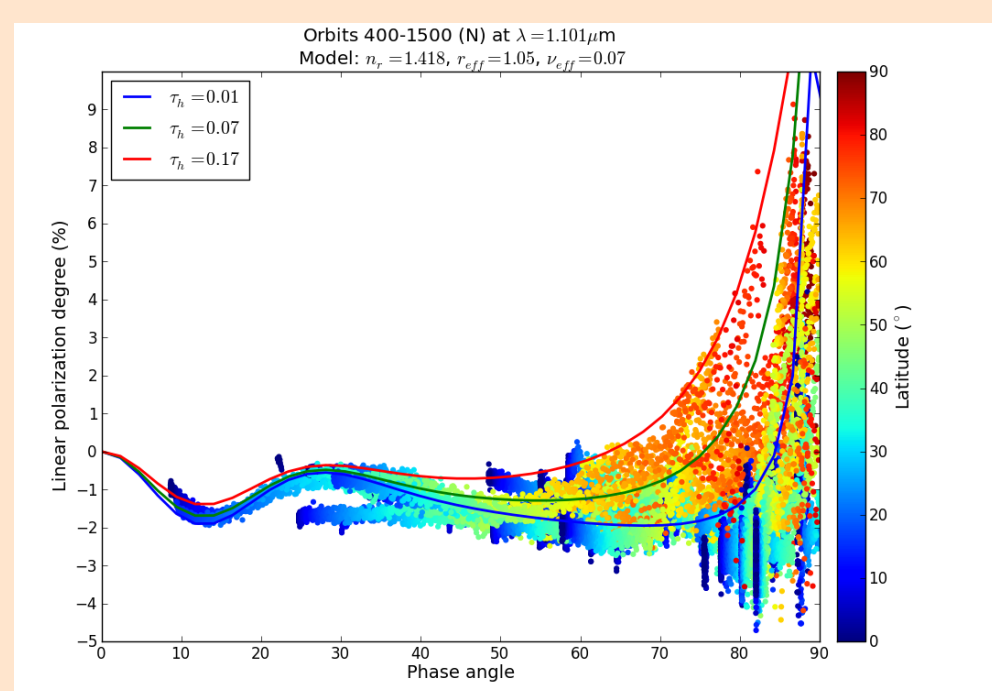


Figure: Polarization of nadir observations in northern hemisphere from orbit 400 to 1500 at  $1.101 \mu\text{m}$  with model  $n_r = 1.418$ ,  $r_{\text{eff}} = 1.05 \mu\text{m}$ ,  $\nu_{\text{eff}} = 0.07$ , and with haze optical depth  $\tau_h = 0.01, 0.07, 0.17$ . Latitude of observation is color-coded.

## 8. CONCLUSION AND PERSPECTIVES

### Conclusion

- SPICAV polarization data is fully exploitable with a **large spatial and temporal coverage**;
- Consistent with previous observations**: same features and order of magnitude;
- The glory is observed every time at phase angles  $\sim 15^\circ$ : spherical micrometric particles constitute most of the clouds of Venus;
- Refractives indices retrieved are **compatible with sulfuric acid solution**;
- An increase of the haze optical thickness is observed with **increasing latitude**.

### Perspectives

- Make use of the spot tracking observations to decouple the latitude and the phase angle;
- Investigate further the temporal and spatial variability.

This work has been submitted to Planetary and Space Science as Rossi et al., *Preliminary study of Venus cloud layers with polarimetric data of SPICAV/VEx*.

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