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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[8] 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.

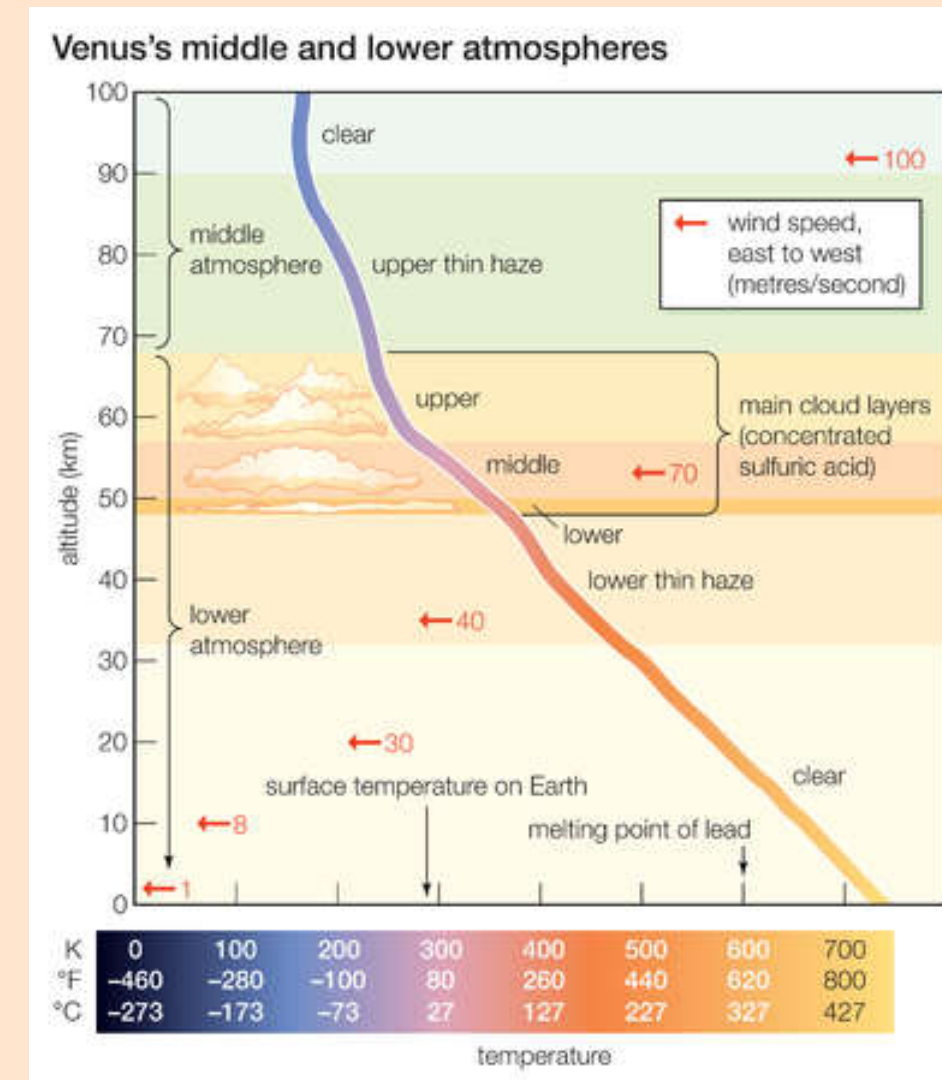


Figure: Structure of Venus clouds

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

Table: Current knowledge of Venus clouds.

2. SPICAV-IR

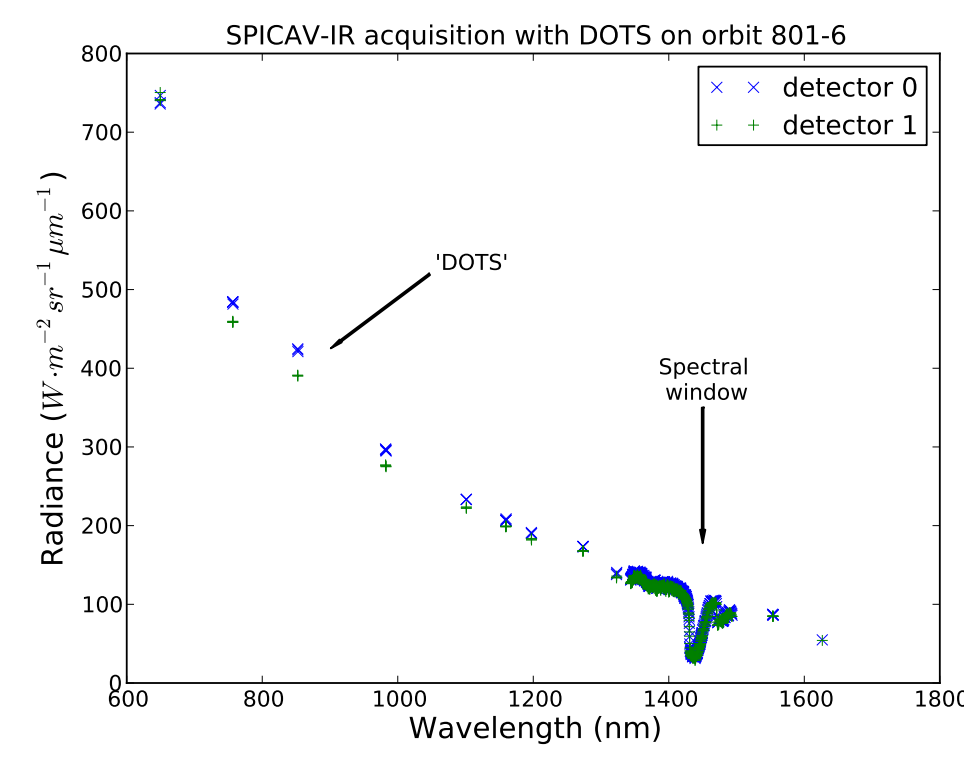


Figure: Example of SPICAV acquisition.

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 performed by knowing that for any wavelength $P_\ell = 0$ at 0° 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[7].

Channel	Coverage
SW	$0.65 \mu\text{m} - 1.05 \mu\text{m}$
LW	$1.05 \mu\text{m} - 1.7 \mu\text{m}$

Table: SPICAV characteristics

3. SPICAV OBSERVATIONS

- Observations performed in nadir, spot-tracking mode and with zig-zags for SO₂ mapping;
- VEx has a north polar orbit: observations mostly located in northern hemisphere;

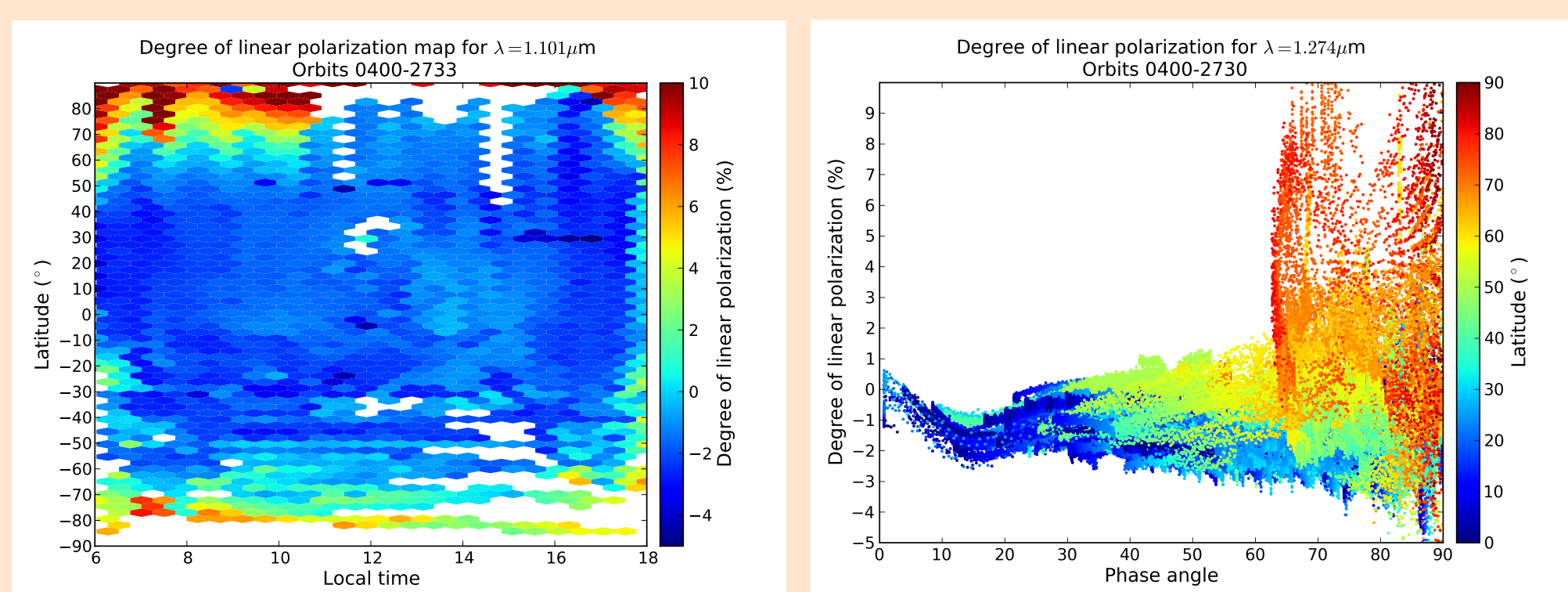


Figure: **Left:** Average maps from SPICAV polarization observations at 1101 nm for all orbits from 2007-05-26 to 2013-10-16. **Right:** Polarization nadir observations at $\lambda = 1.274 \mu\text{m}$ for the same period as a function of phase angle and latitude. The glory is visible at $\sim 15^\circ$ 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 sometimes higher than +10%;
- A phenomenon known as **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[5, 6].

4. CLOUD MODEL

- The cloud model has a layer of haze above a cloud layer, each homogeneously mixed;
- Polarization retrieved with the doubling-adding method[9];
- 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 τ_h at higher phase angles**.

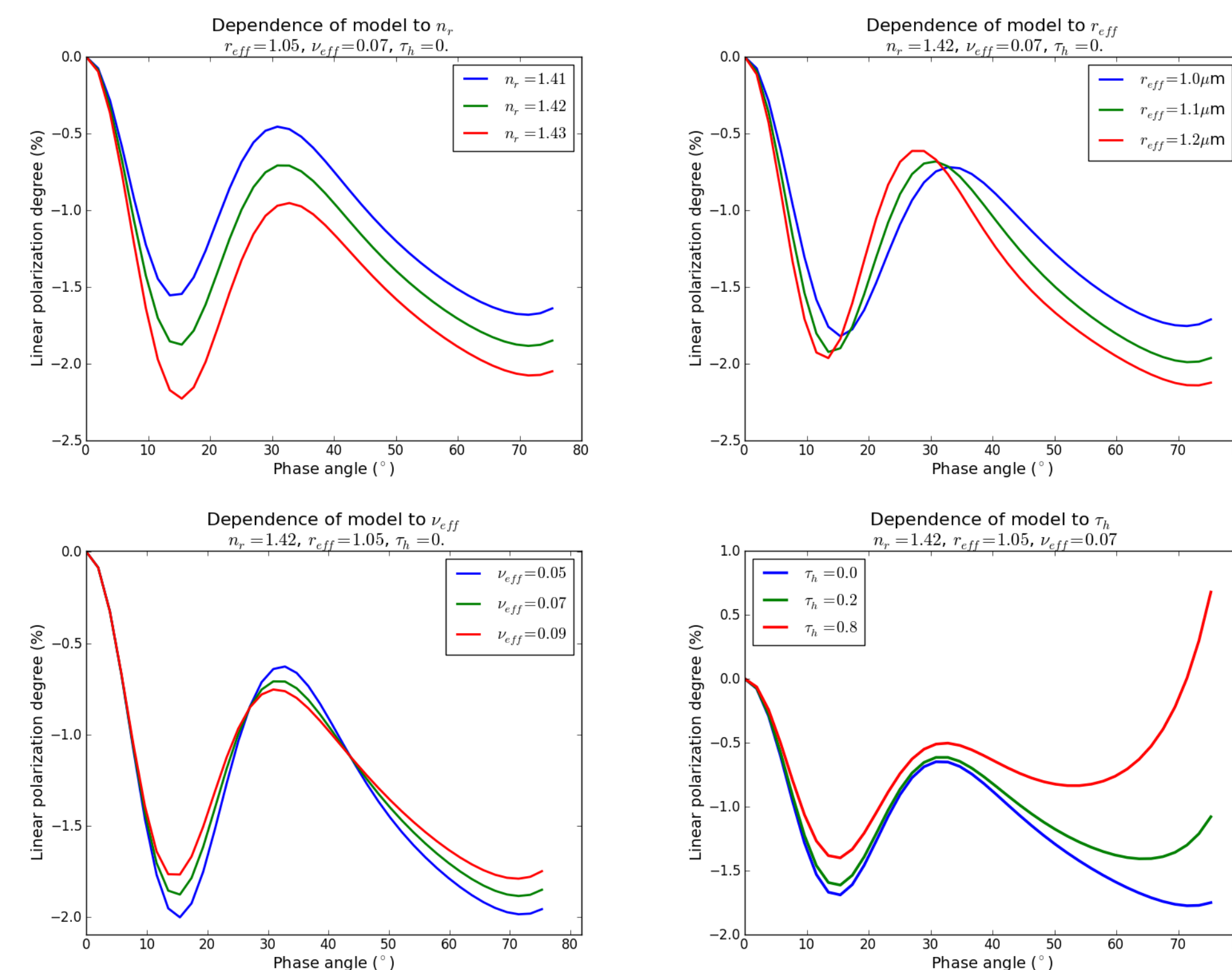


Figure: Illustration of the influence of the cloud parameters n_r , r_{eff} , ν_{eff} , and τ_h on the model.

5. GLORY ANALYSIS

Cloud parameters n_r , r_{eff} , ν_{eff} retrieved from 10 selected glories using our model at six wavelengths simultaneously (1.101, 1.16, 1.198, 1.274, 1.324 and $1.553 \mu\text{m}$).

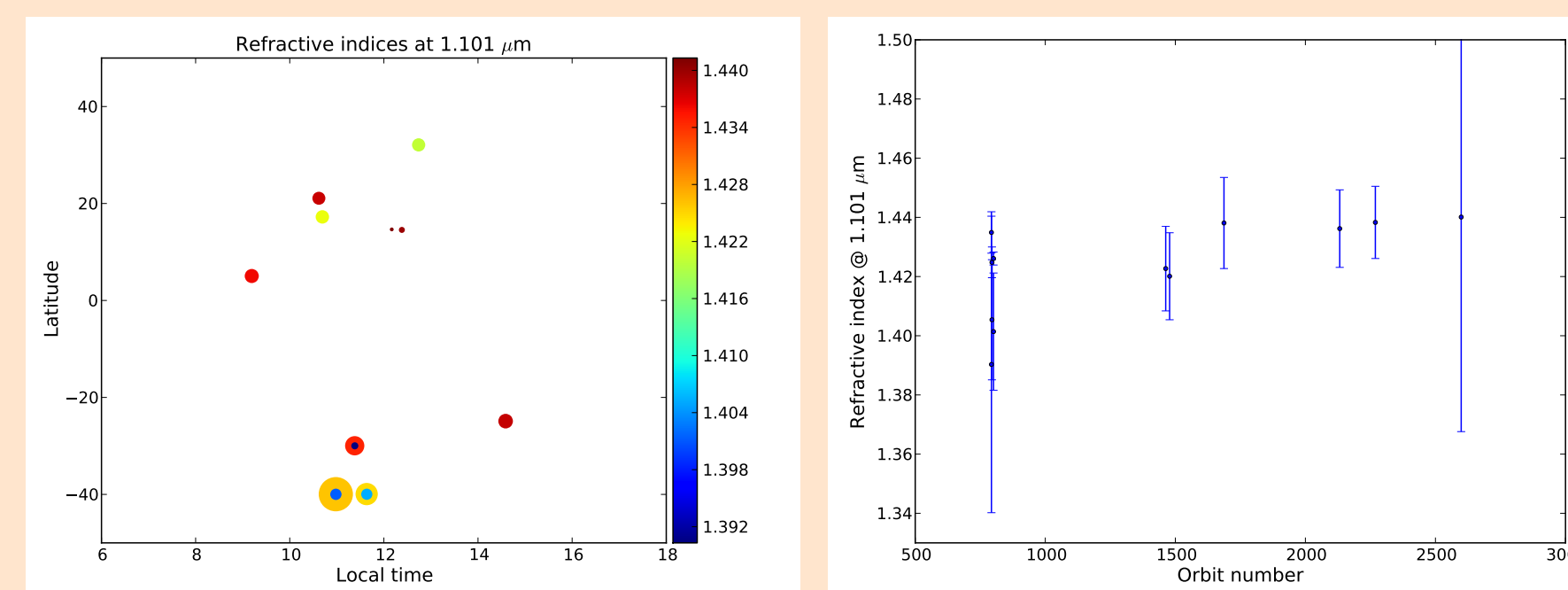


Figure: Retrievals of refractive indices from glory observations as a function of (from left to right) latitude/local time and orbit number. Size of marker is inversely proportional to uncertainty.

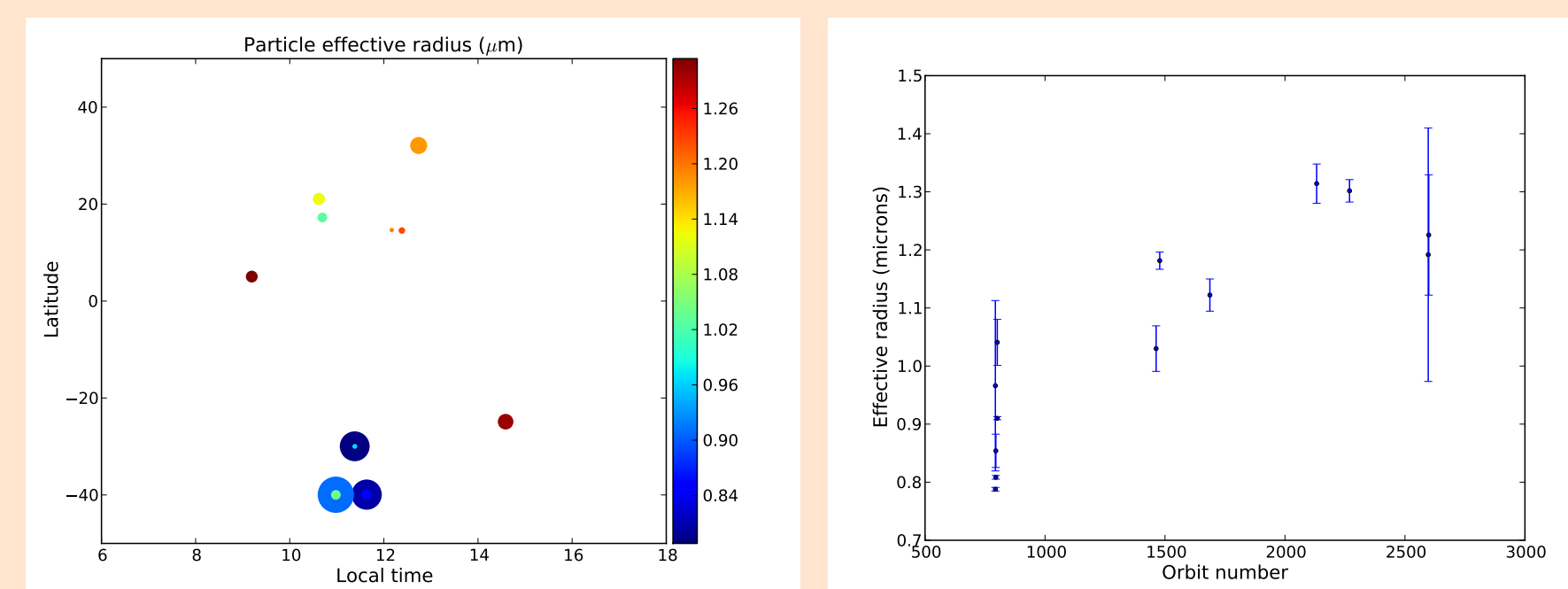


Figure: Retrievals of effective radii from glory observations as a function of (from left to right) latitude/local time and orbit number. Size of marker is inversely proportional to uncertainty.

- Refractive indices of $n_r \sim 1.44$ at $\lambda = 1.1 \mu\text{m}$, **compatible with concentrated H₂SO₄ solution**;
- Particle effective radius varying in range $0.8 < r_{\text{eff}} < 1.3 \mu\text{m}$;
- Upper limit on variance of the size distribution: $\nu_{\text{eff}} < 0.15$;
- Small haze column densities required $C_h < 1 \mu\text{m}^{-2}$ **at low latitudes**.
- Too few usable glories to make any conclusion regarding latitudinal or local time trends. Possible increase of n_r and r_{eff} with time.

6. HIGHER LATITUDES

- At higher latitudes, thicker haze is required to match observed polarization.
- A fixed composition of the cloud layer is assumed in order to derive the haze column density. For the cloud $r_{\text{eff}} = 1.05 \mu\text{m}$, $\nu_{\text{eff}} = 0.07$ and $n_r = 1.44$ at $1.101 \mu\text{m}$.
- The haze effective radius and variance are set to $r_{\text{eff}} = 0.25 \mu\text{m}$ and $\nu_{\text{eff}} = 0.25$.
- Fits performed at all latitudes in the northern hemisphere;
- The properties of the clouds change with latitude, with increasing haze column density with increasing latitude**. This is in agreement with OCPP measurements.
- A small decrease of C_h occurs between equator and 50° of latitude, followed by a sharp increase towards the pole.
- Kawabata[2], observed an increase in the haze column density with increasing latitude (from $0.23 \mu\text{m}^{-2}$ at low latitudes to $3.1 \mu\text{m}^{-2}$ at high latitudes). Our values fall within this range.

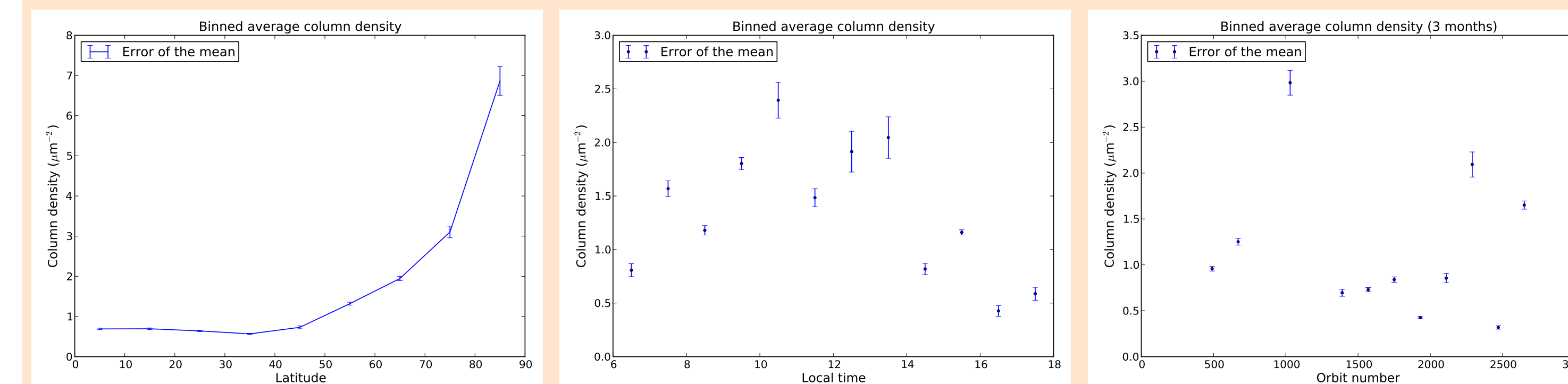


Figure: Binned averaged values of haze column density as a function of (from left to right) latitude, local time and orbit number.

7. 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 column density** is observed **with increasing latitude**.

Perspectives

- Investigate further the temporal and spatial variability, in particular for the haze column density;
 - Possible information on vertical structure of the clouds from polarimetry in the CO₂ absorption band.
- For further information on the instrument and/or method, please refer to **Rossi et al. 2014** (in press) [7].

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