

Context

- Since 1929, polarization has been used to characterize Venus' clouds and hazes refractive index, size and 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 on Venus Express.

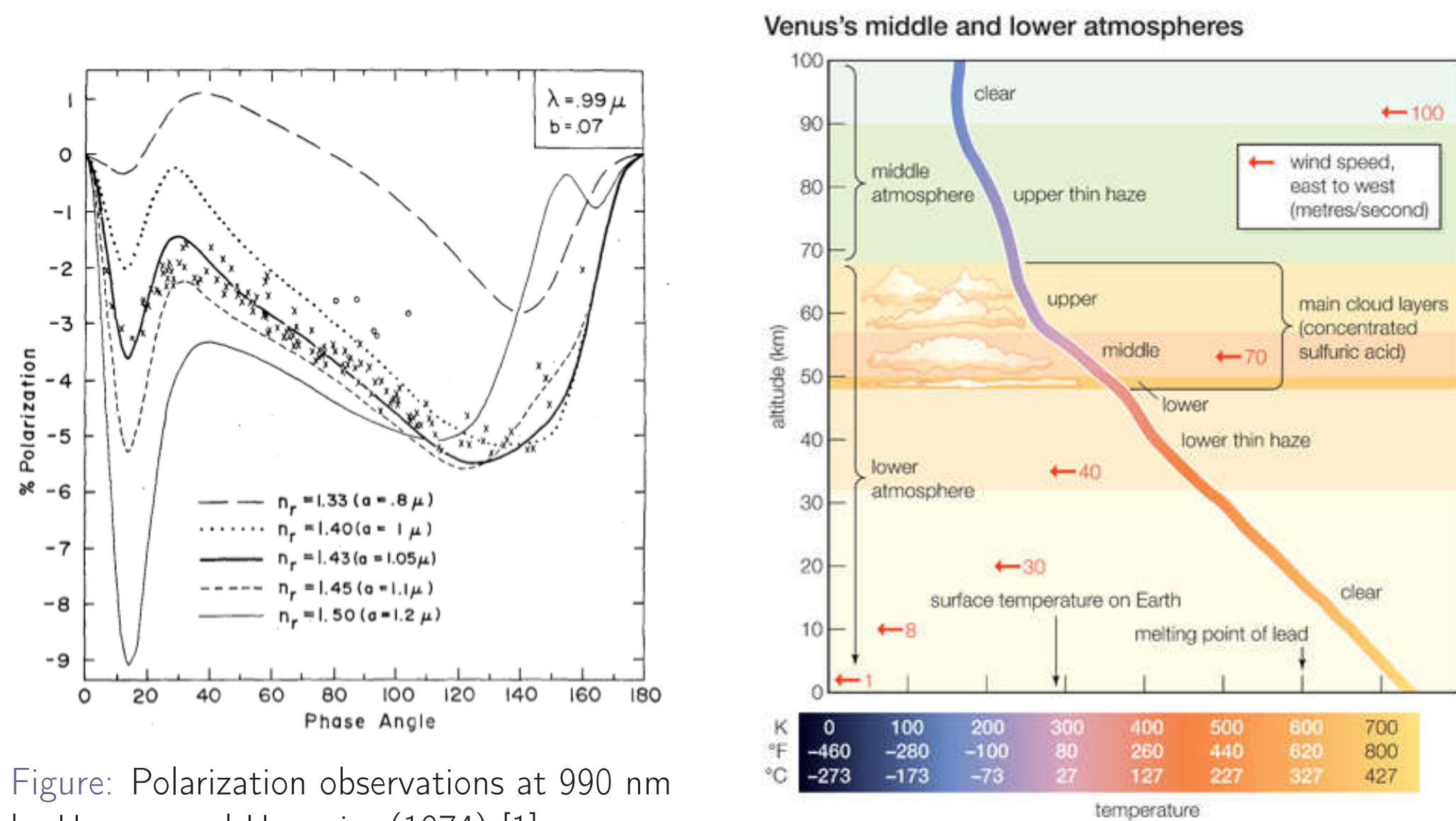


Figure: Polarization observations at 990 nm by Hansen and Hovenier (1974) [1].

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.

Scattering processes

Depending on the radius r and the wavelength of observation, different scattering processes are involved. They can be distinguished with the *size parameter* $x = \frac{2\pi r}{\lambda}$.

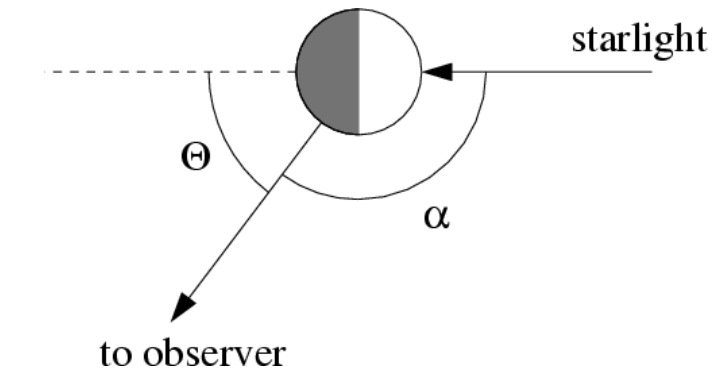


Figure: Illustration of the scattering angle Θ and the phase angle α .

- **Rayleigh regime** ($x \ll 1$) : Isotropic diffusion, cross-section $\propto 1/\lambda^4$. Linear polarization is +100% for $\alpha = 90^\circ$
- **Mie regime** ($x \geq 1$) : Strong forward scattering; dependence in n and x . Polarization patterns are much more complicated : generate optical features such as glories at low phase angles. Particle size distribution described by r_{eff} , mean radius and ν_{eff} variance of the distribution.

Mie model

- Model based on spherical drops with $n_i \sim 0$;
- $x \rightarrow 0$: Rayleigh regime;
- Glory : strong negative polarization feature near 20° .

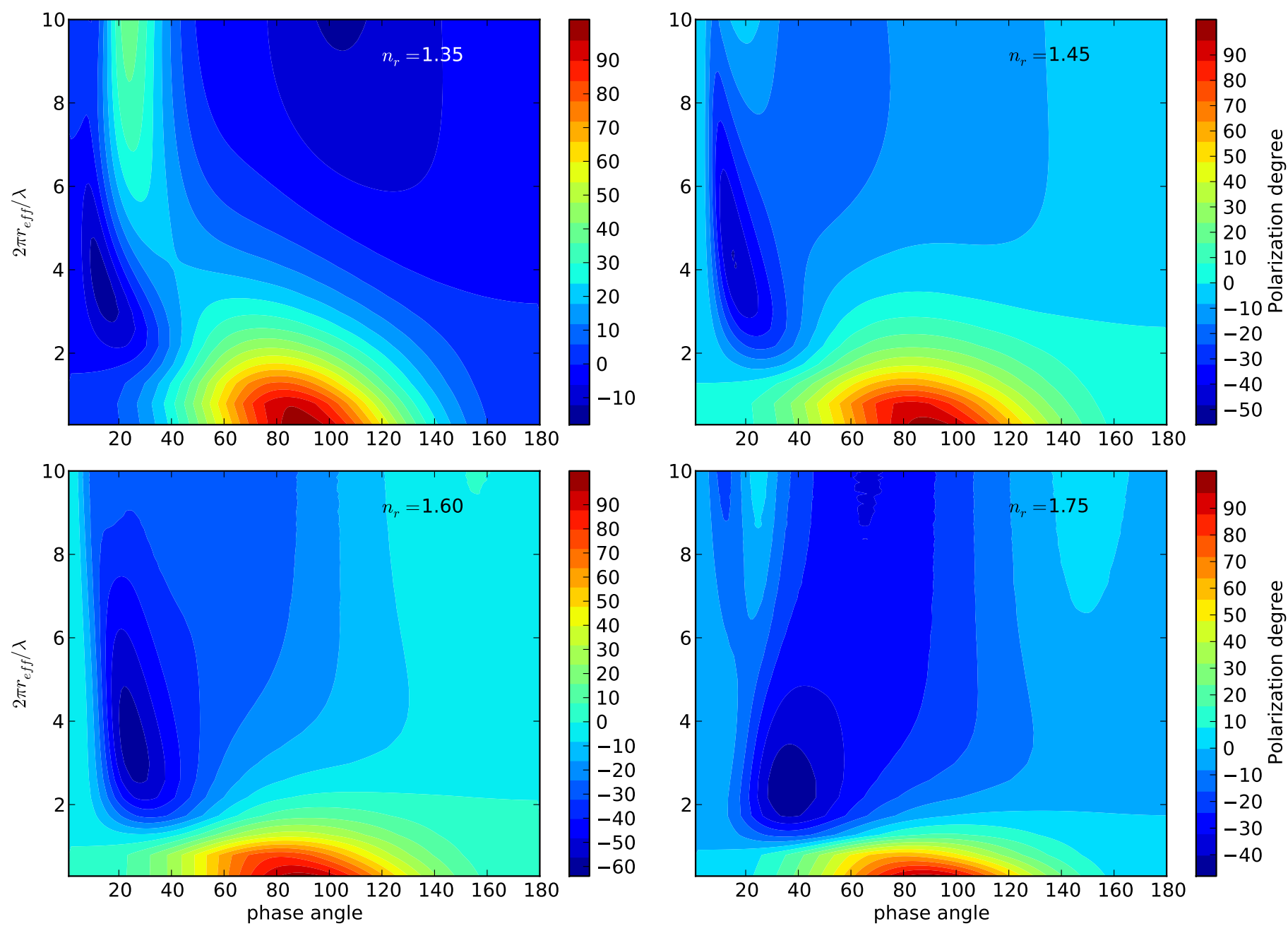


Figure: Linear polarization degree in function of phase angle and size parameter for four values of refractive index.

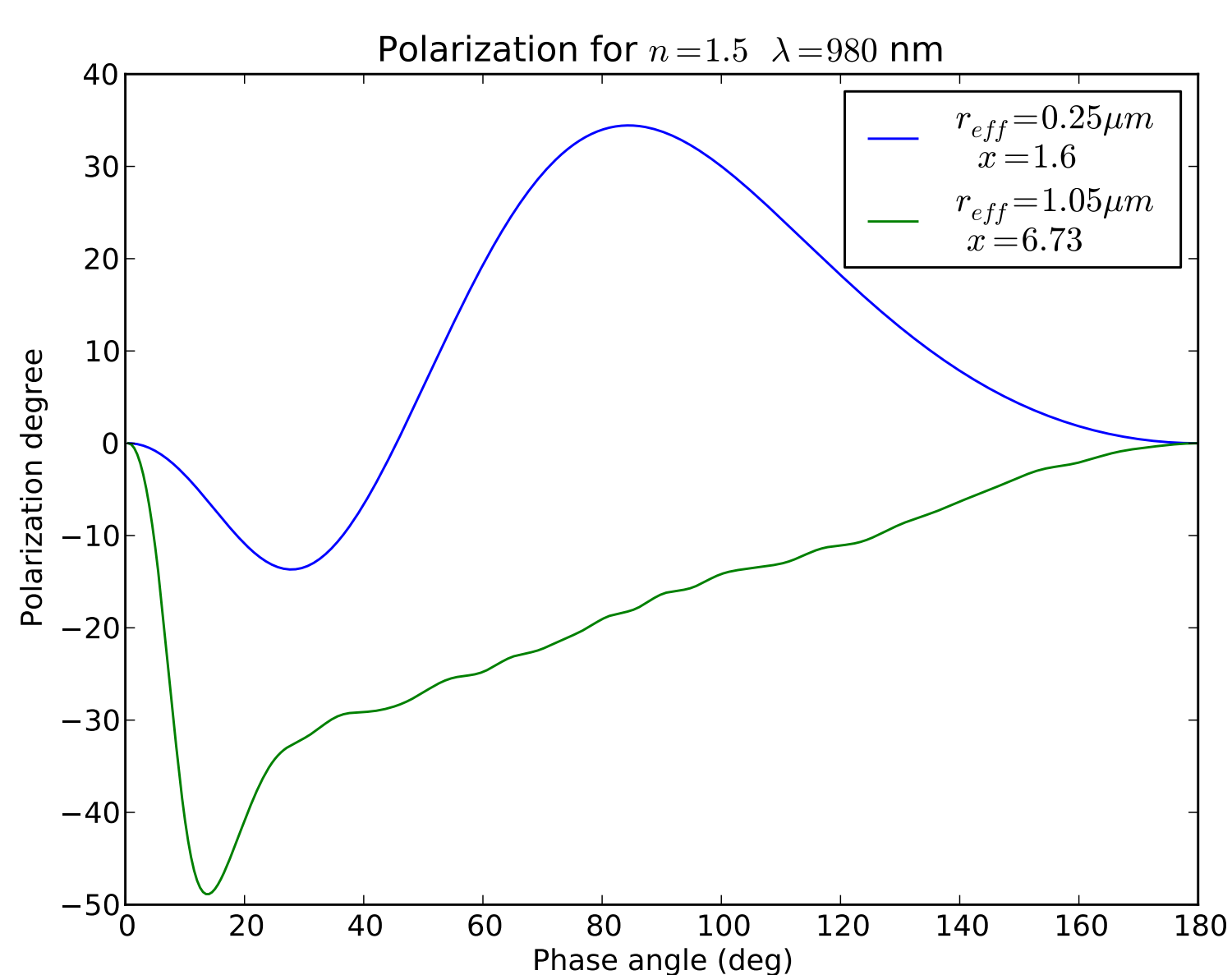


Figure: Example of two polarization profiles for different values of x . In blue, the curve has a Rayleigh-like behaviour; in green, the curve shows the Mie regime with a glory at about 15 degrees.

SPICAV

SPICAV 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 linear polarization degree :

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

Cross-calibration can be performed by knowing that for any wavelength $P_\ell(\alpha = 0) = 0$. 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.

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

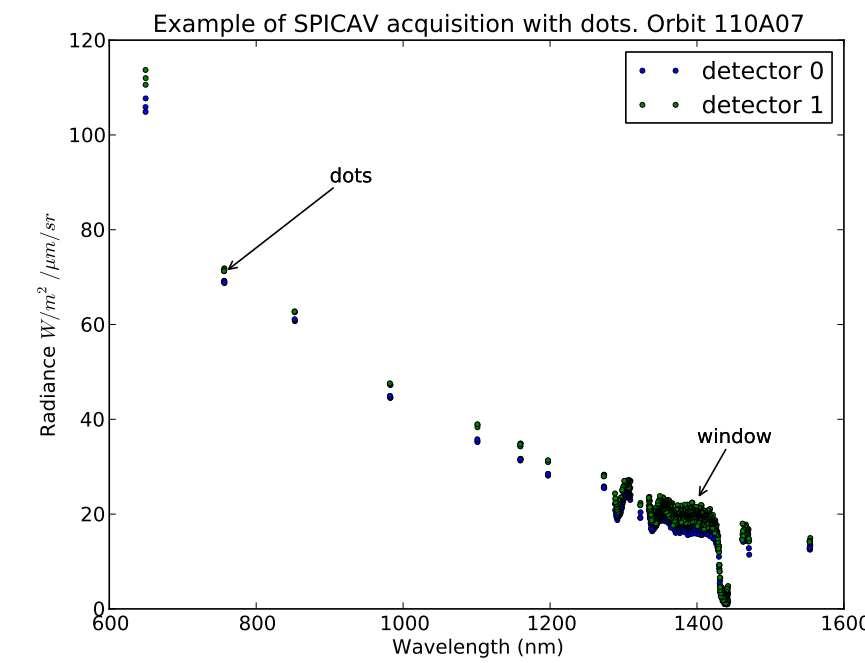


Figure: Example of SPICAV acquisition.

SPICAV observations

- Observations done in nadir mode;
- Mostly located on day-side and in northern hemisphere;
- Up to 14 wavelengths available.

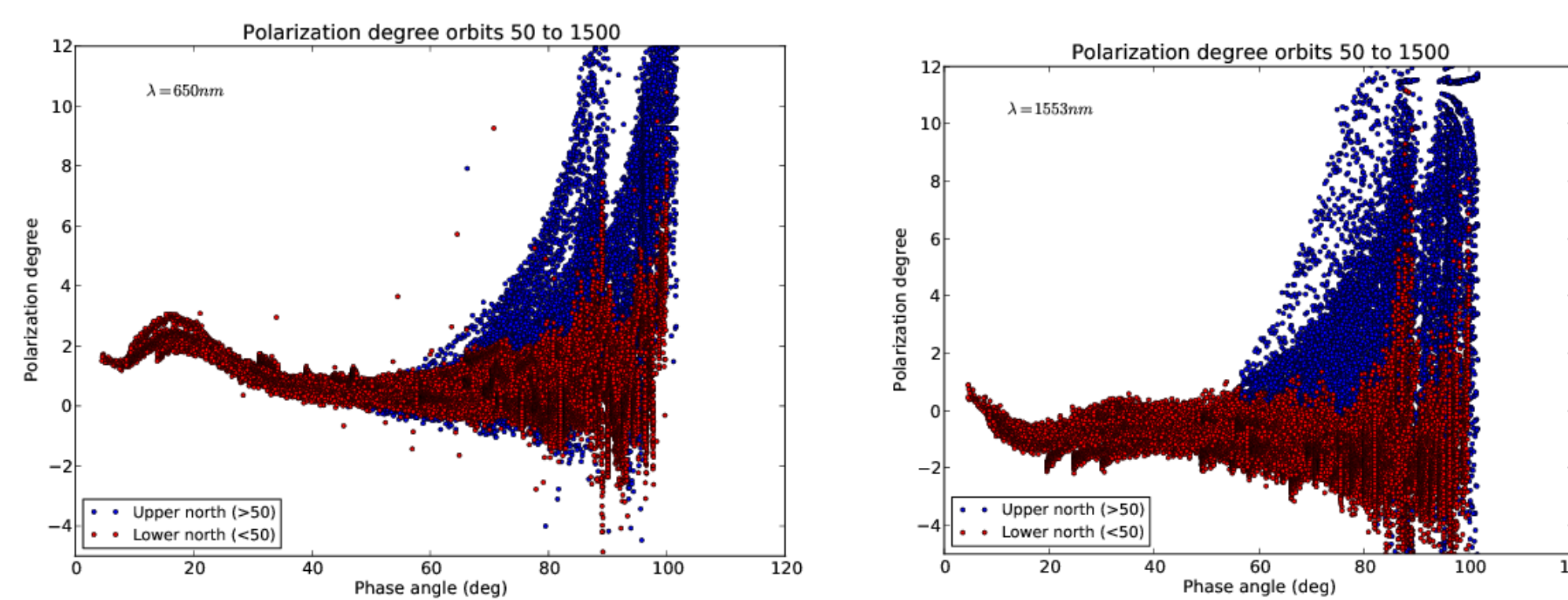


Figure: SPICAV polarization observations at 650 nm and 1553 nm for all orbits 50 to 1500. The data show strong polarization for phase angles near 90° .

- Strong positive polarization at phase angles near 90° and wavelengths $> 1 \mu\text{m}$ not compatible with $r \sim 1 \mu\text{m}$ particles.
- Rayleigh-like scatterers as the hazes ($r \sim 0.25 \mu\text{m}$) are necessary.
- Their influence is more visible at high latitudes which indicates a latitudinal variability with more hazes at higher latitudes.

The glory is visible in SPICAV observations at low phase angles. Only a few observations cover a full glory. These features were observed by VMC, also onboard Venus Express.

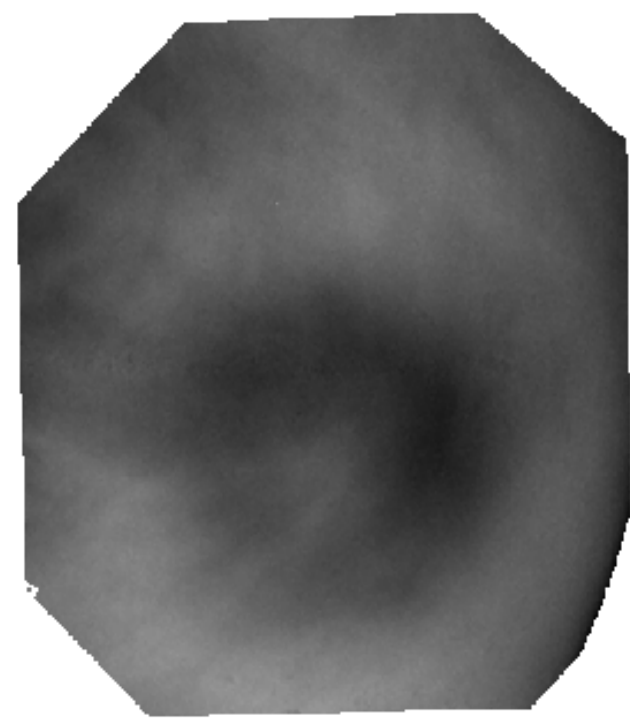


Figure: A glory as seen by the Venus Monitoring Camera.

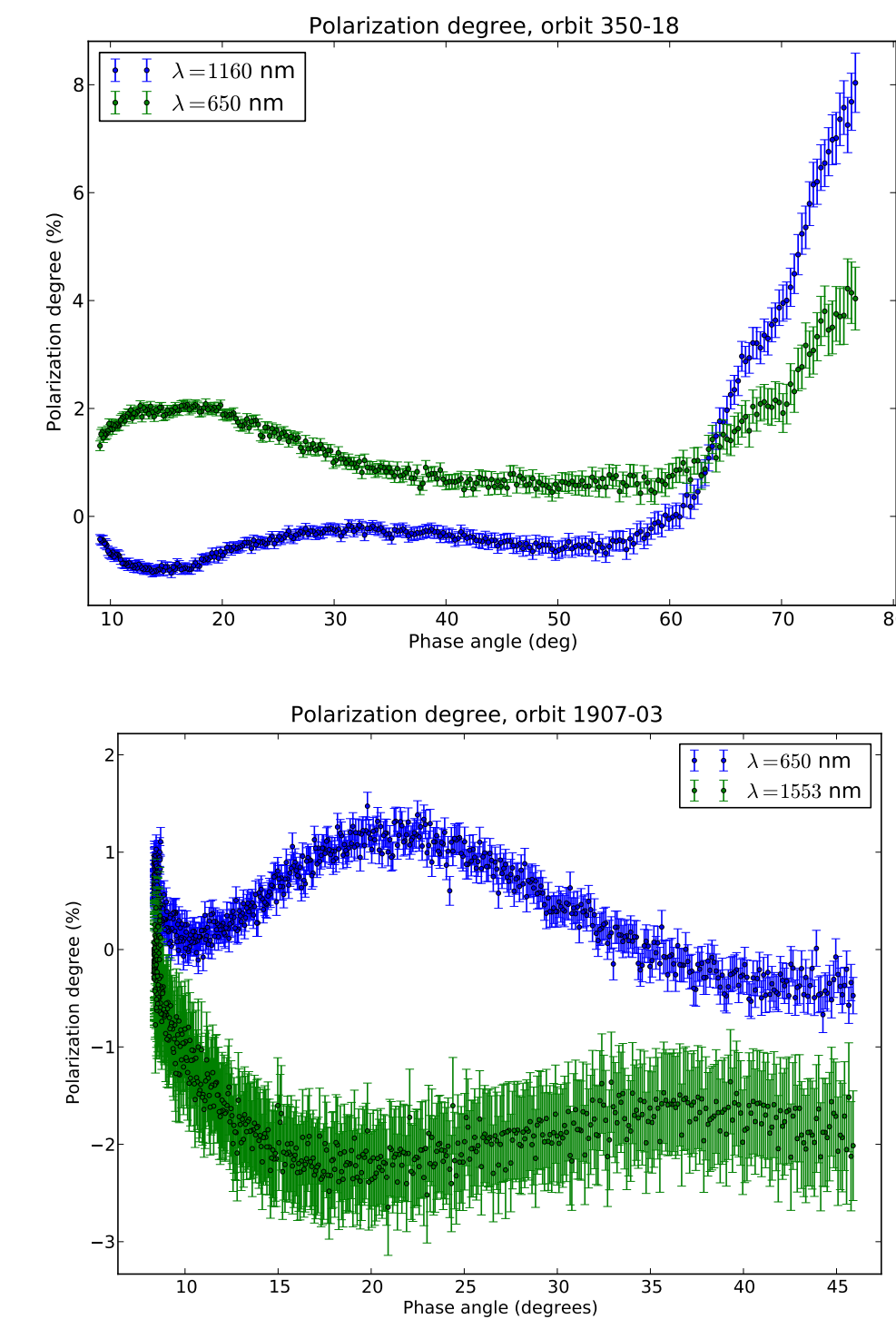


Figure: **Above** : Polarization observation for orbit 350-18 with error bars at 650 nm and 1553 nm. **Below** : Same observations, for orbit 1907-03.

Glory analysis

The glory position and shape is dependent on values of n_r , r_{eff} and ν_{eff} . We can use this property to constrain the refractive index under a single scattering assumption. To take into account the "damping" caused by multiple scattering, we use a scaling parameter.

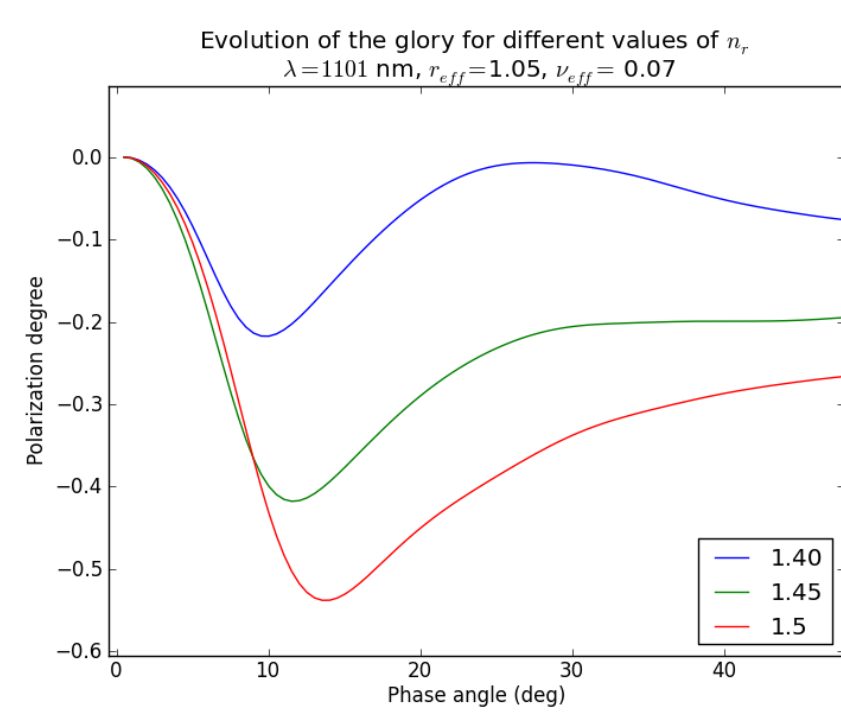


Figure: Evolution of the glory with respect to the value of n_r . For $\lambda = 1101 \text{ nm}$, $r_{eff} = 1.05 \mu\text{m}$ and $\nu_{eff} = 0.07$.

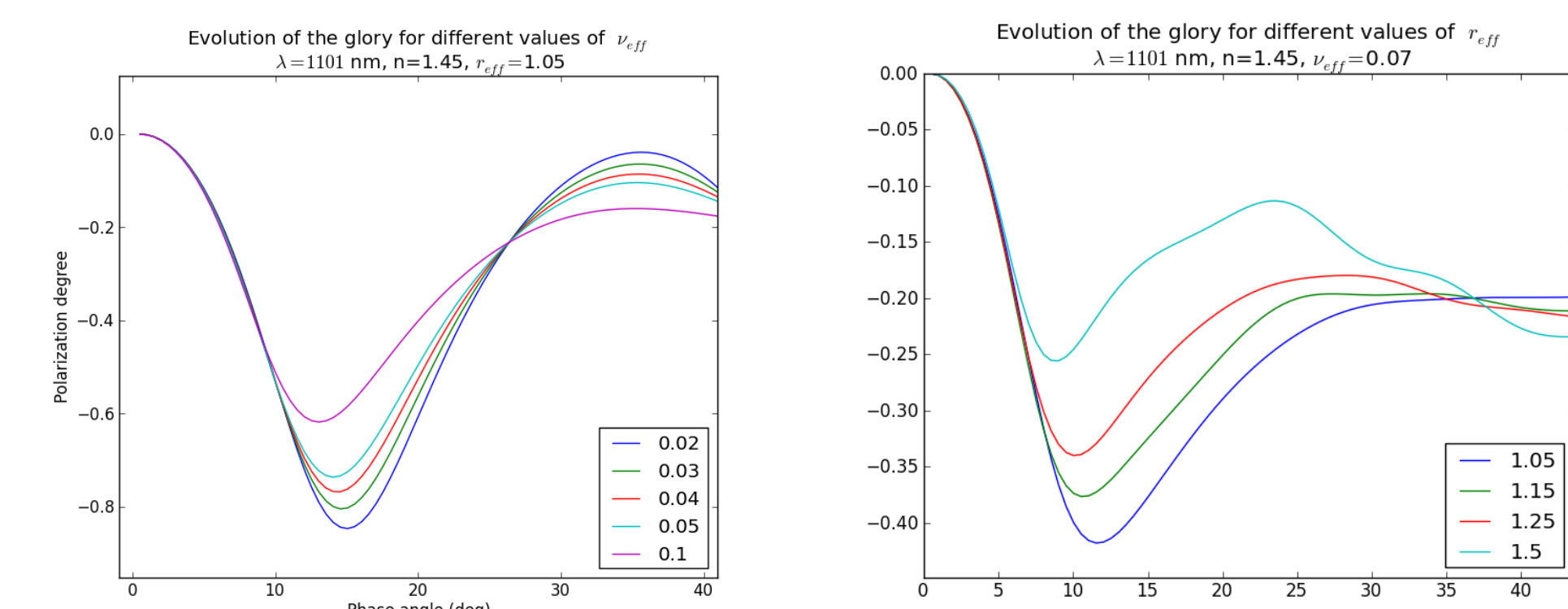


Figure: **Left** : Glory evolution with respect to the variance ν_{eff} at $\lambda = 1101 \text{ nm}$, for $n_r = 1.45$, $r_{eff} = 1.05$. **Right** : Glory evolution for different values of r_{eff} at $\lambda = 1101 \text{ nm}$, with $n_r = 1.45$ and $\nu_{eff} = 0.07$.

For given values of radius and variance, we try to find the index which gives best agreement with the observed position and shape of the glory.

Preliminary results

We applied our model on some glories observed by SPICAV. Some preliminary fits are presented below. In all fits, n_r is fitted by the position of the glory, r_{eff} is fixed at $1.05 \mu\text{m}$, while ν_{eff} is adjusted to improve the fit of the shape of the glory.

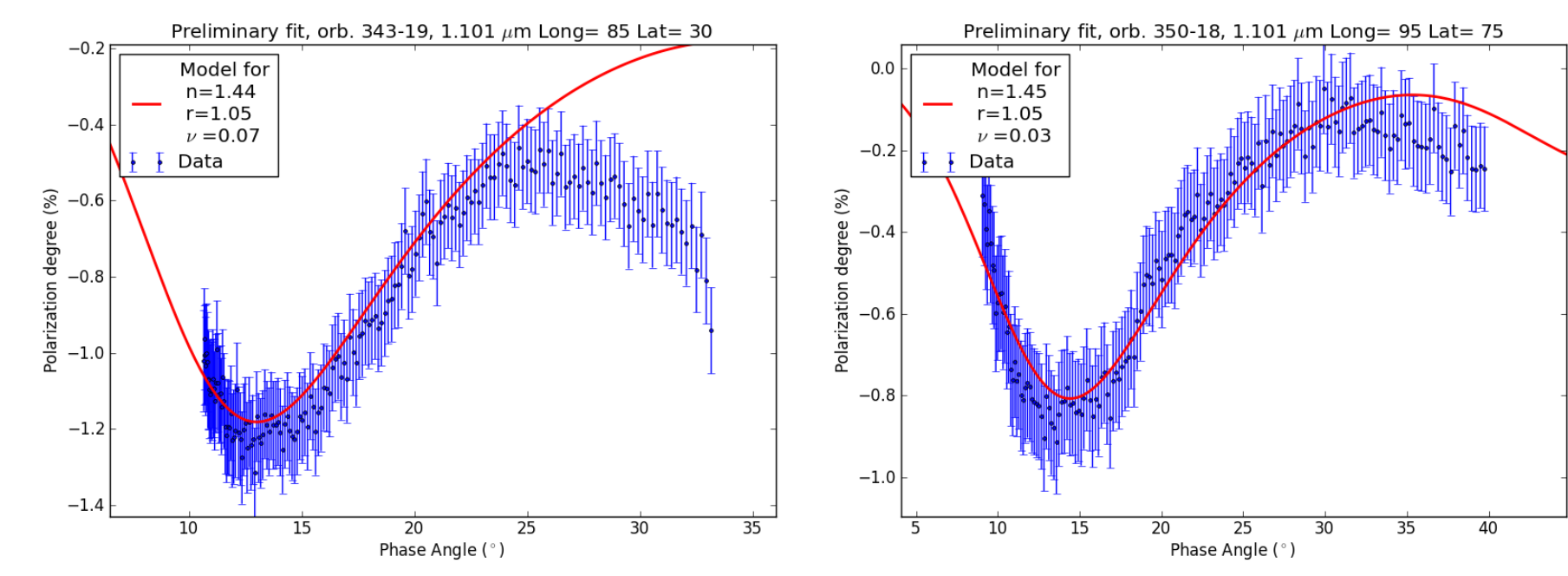


Figure: Fits on orbits 343-19 (left) and 350-18 (right) at $\lambda = 1.101 \mu\text{m}$ with cloud particles ($r_{eff} = 1.05 \mu\text{m}$). The best fits are for ($n = 1.44 \pm 0.01$, $\nu_{eff} = 0.07$) and ($n = 1.45 \pm 0.01$, $\nu_{eff} = 0.03$) respectively.

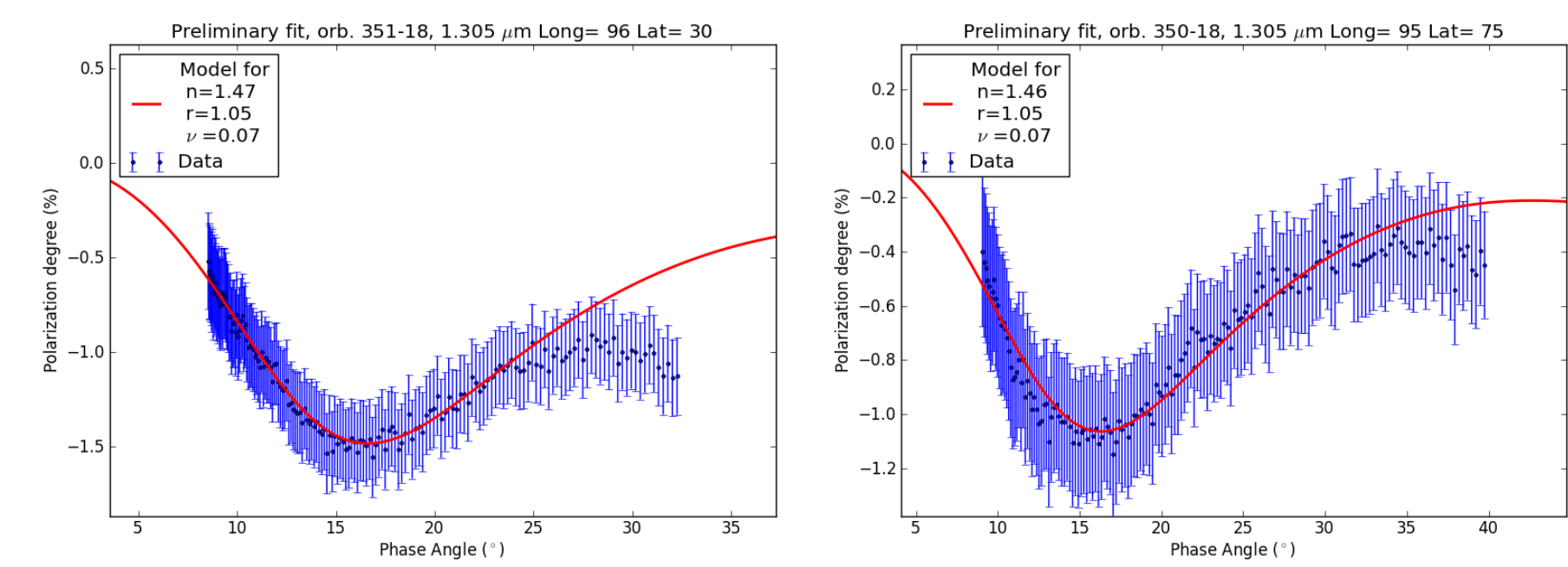


Figure: Fits on orbits 351-18 (left) and 350-18 (right) at $\lambda = 1.305 \mu\text{m}$ with $r_{eff} = 1.05 \mu\text{m}$. The best fits are for ($n = 1.47 \pm 0.01$, $\nu_{eff} = 0.07$) and ($n = 1.46 \pm 0.01$, $\nu_{eff} = 0.07$) respectively.

- Models in agreement with $1.05 \mu\text{m}$ H₂SO₄ droplets;
- Discrepancies between the model and the observations at phase angles above 25° might be caused by the single-scattering approximation and the need to take the geometry into account;
- Nevertheless these fits show that the glory position and shape correspond to the spherical $1 \mu\text{m}$ cloud layer particles.

Conclusion and perspectives

Conclusion

- SPICAV polarization data is fully exploitable;
- Coherent with previous observations : same features and order of magnitude;
- Good coverage in latitude, phase angle and time : possible study of variations;
- Glories are a tool to constrain n_r , r_{eff} and ν_{eff} in the main cloud layer.

Perspectives

- Make more studies of the glories under the single scattering assumption;
- Integrate the Mie model into a polarized radiative transfer model to fit the observations;
- Make use of the spot tracking observations to decouple the SZA and the phase angle;
- Investigate the temporal and spatial variability, particularly the latitudinal structure.

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