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A spectropolarimetric approach for aerosol and cloud analysis

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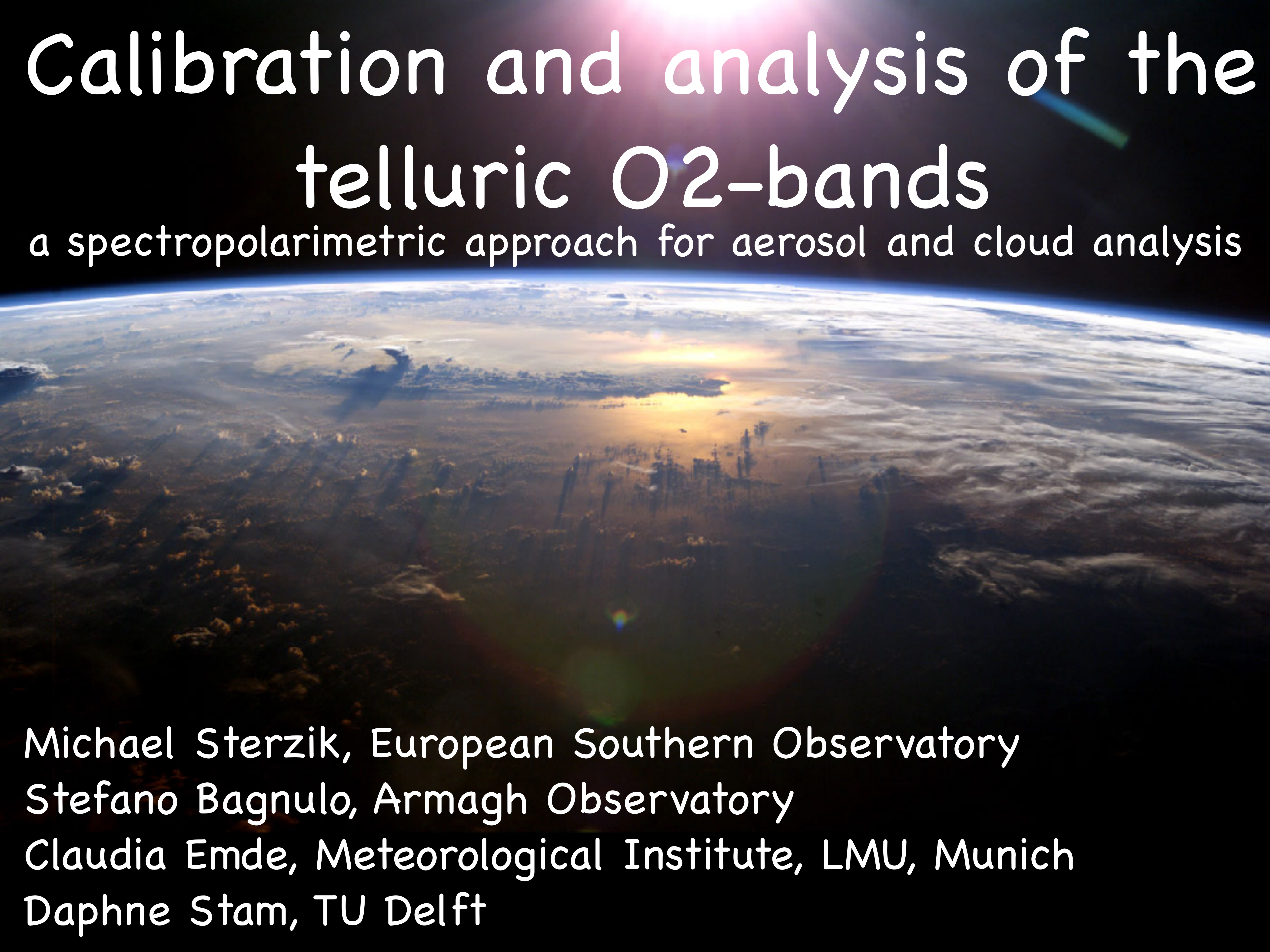


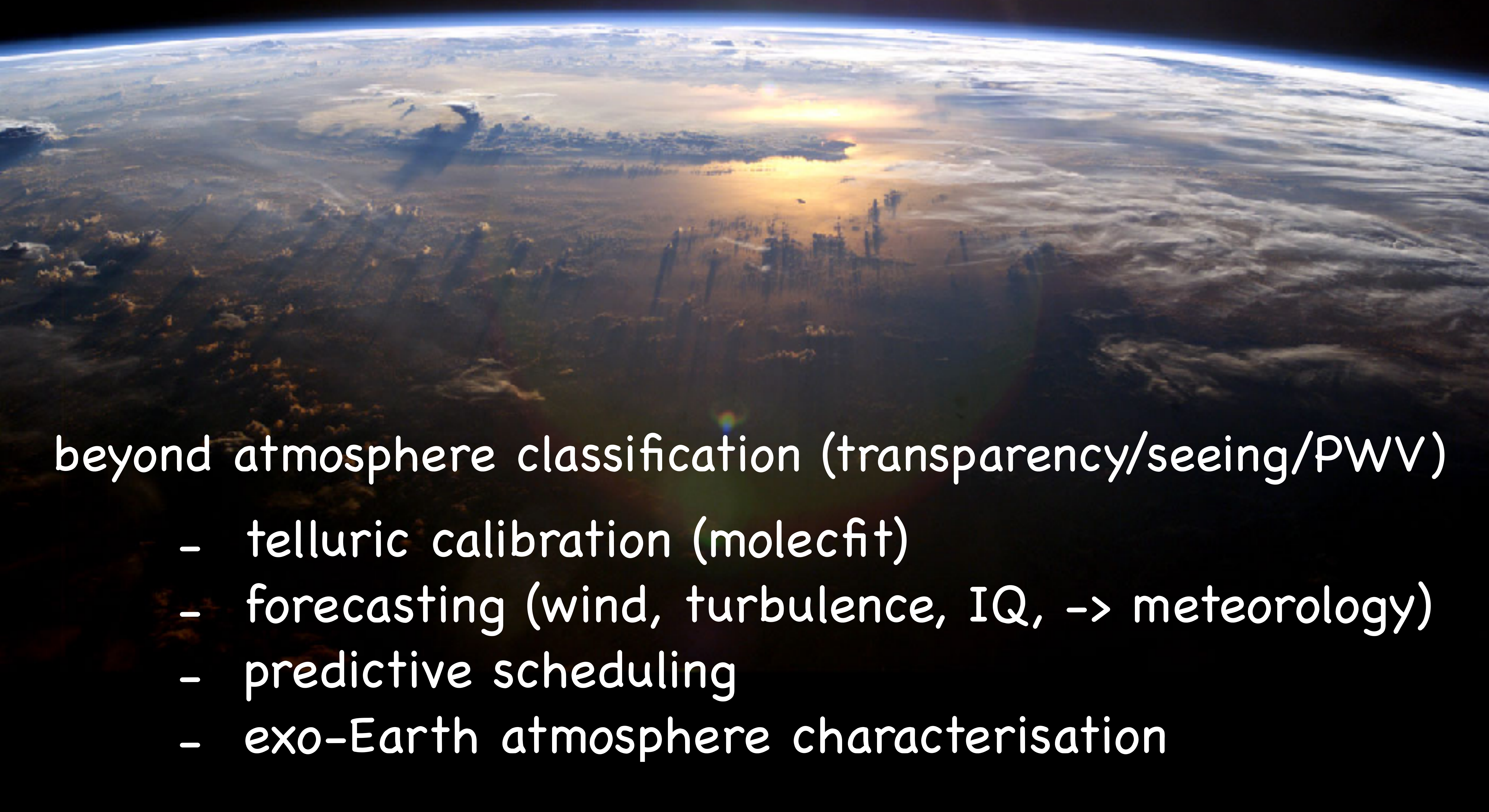
Calibration and analysis of the telluric O2-bands

a spectropolarimetric approach for aerosol and cloud analysis

Michael Sterzik, European Southern Observatory
Stefano Bagnulo, Armagh Observatory
Claudia Emde, Meteorological Institute, LMU, Munich
Daphne Stam, TU Delft

Observatory/Astronomy relevance

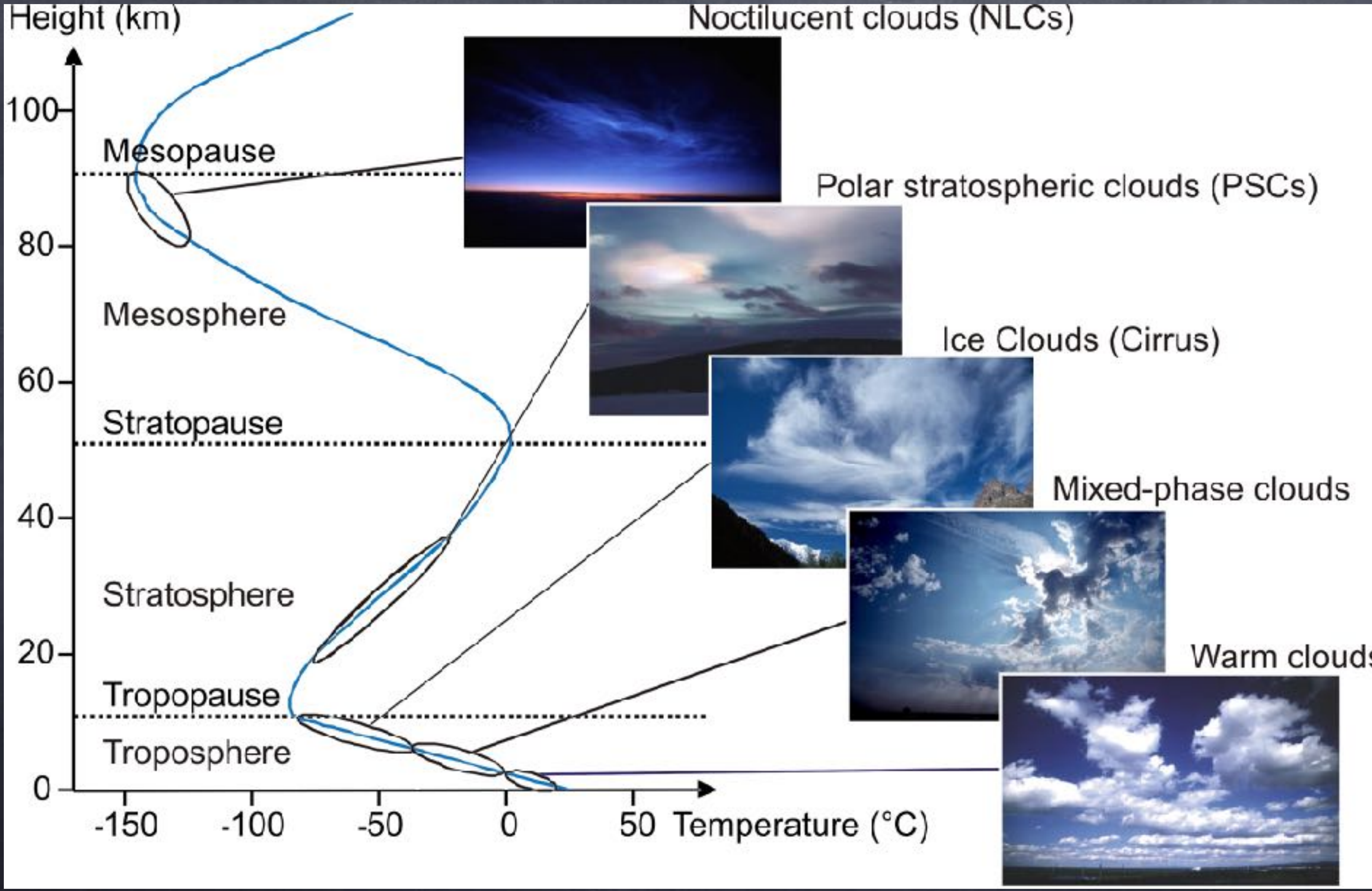
:



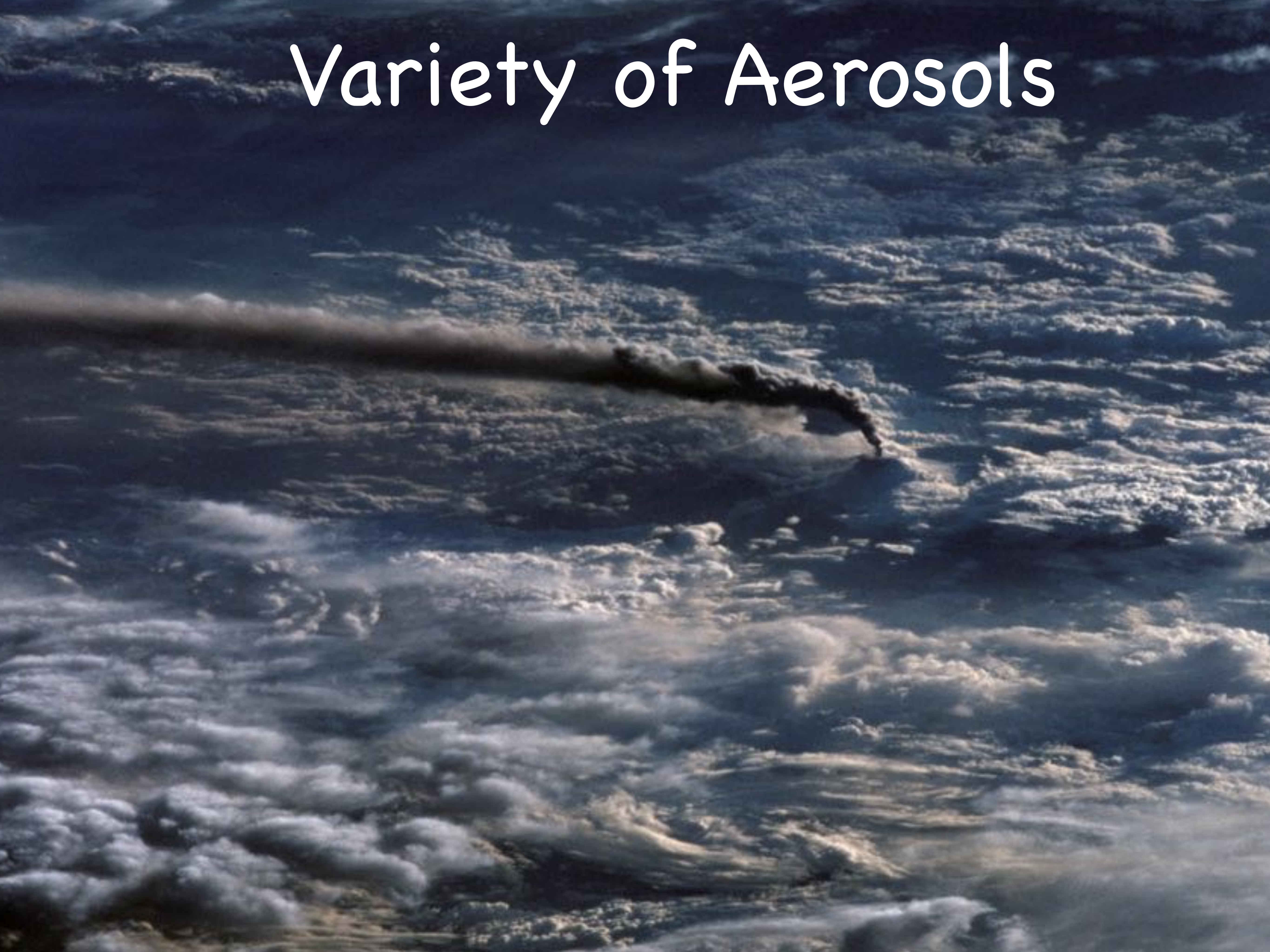
beyond atmosphere classification (transparency/seeing/PWV)

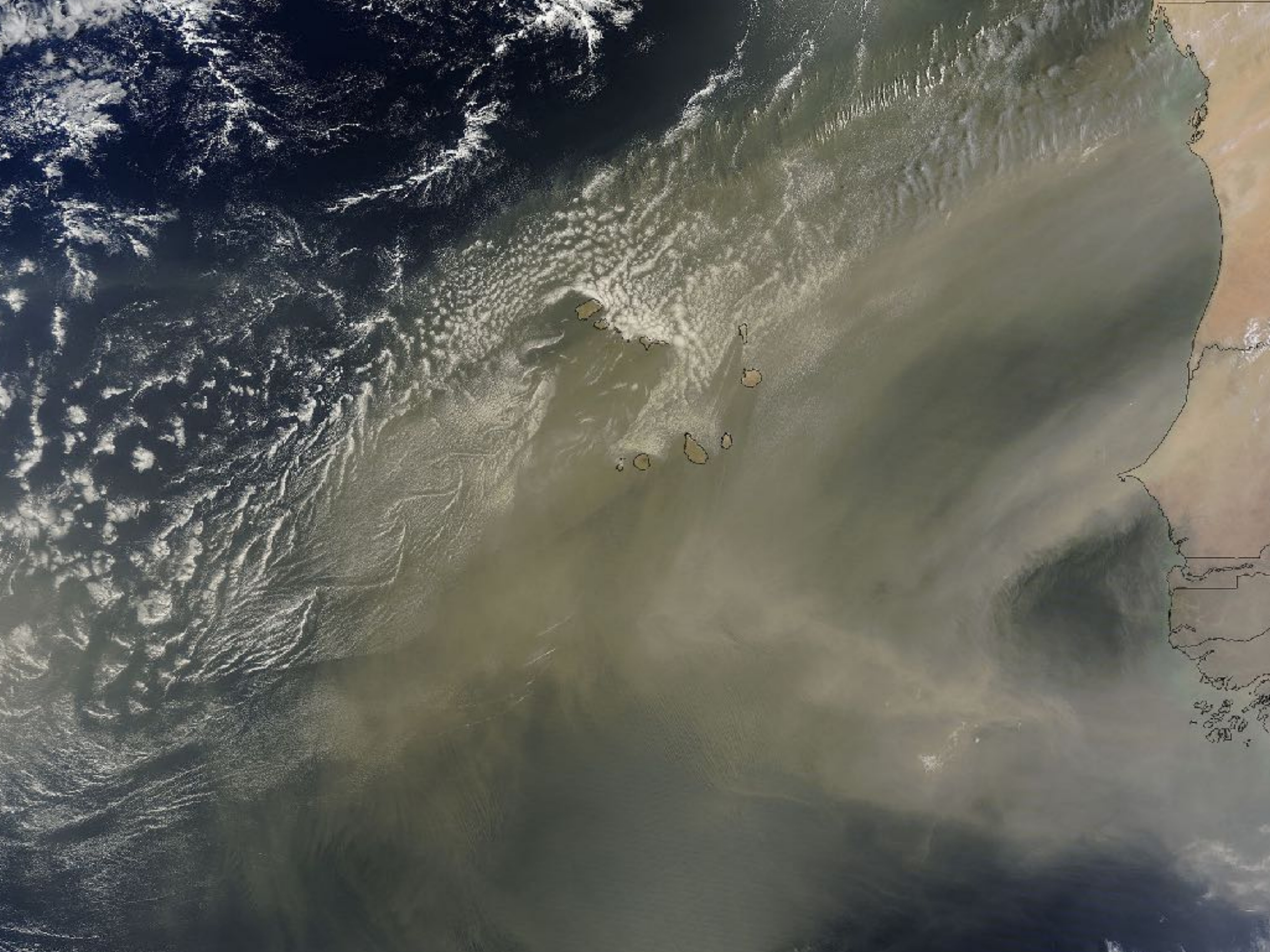
- telluric calibration (molecfit)
- forecasting (wind, turbulence, IQ, -> meteorology)
- predictive scheduling
- exo-Earth atmosphere characterisation

Earth Cloud Systems

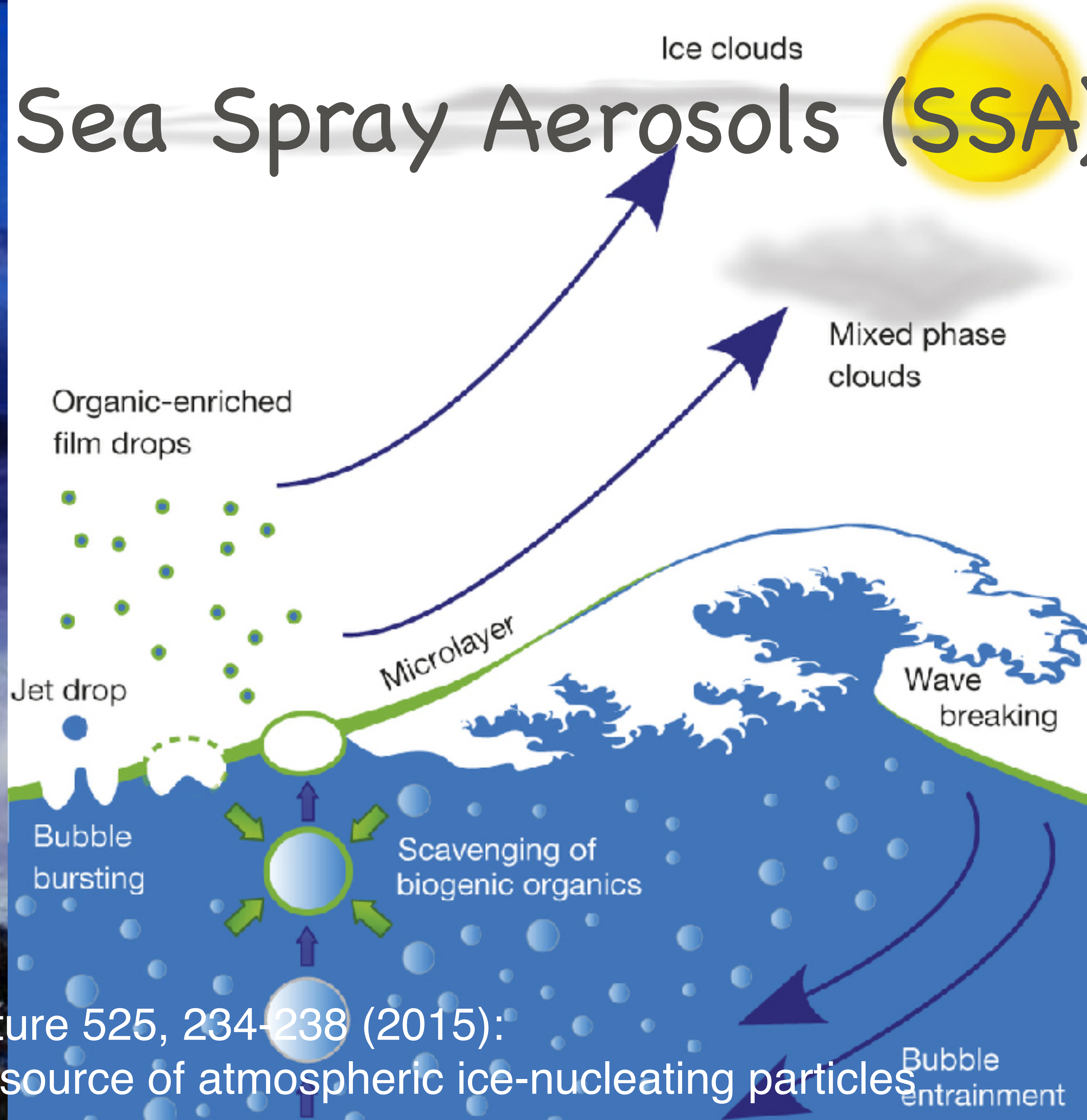


Variety of Aerosols





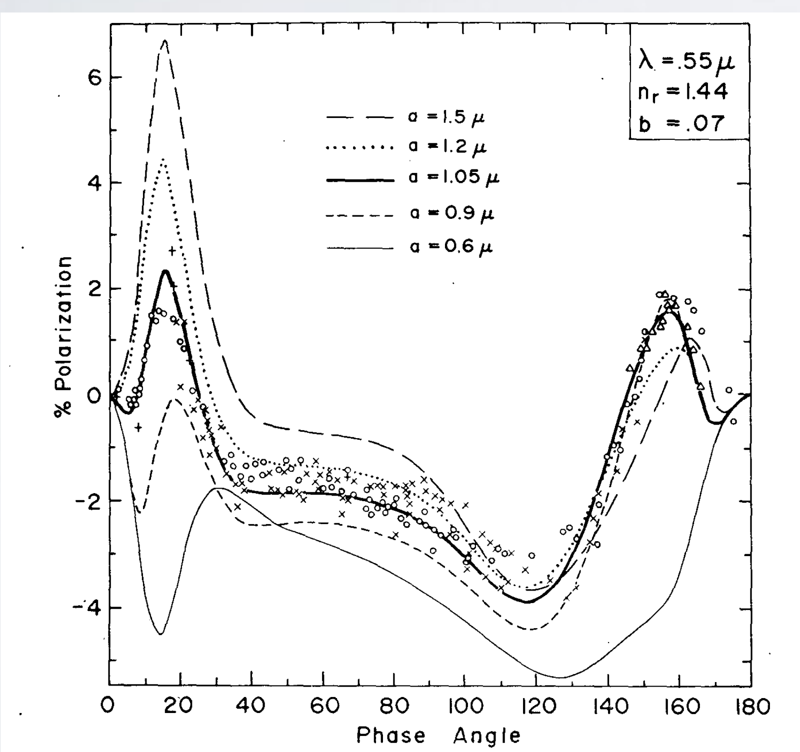
Sea Spray Aerosols (SSA)

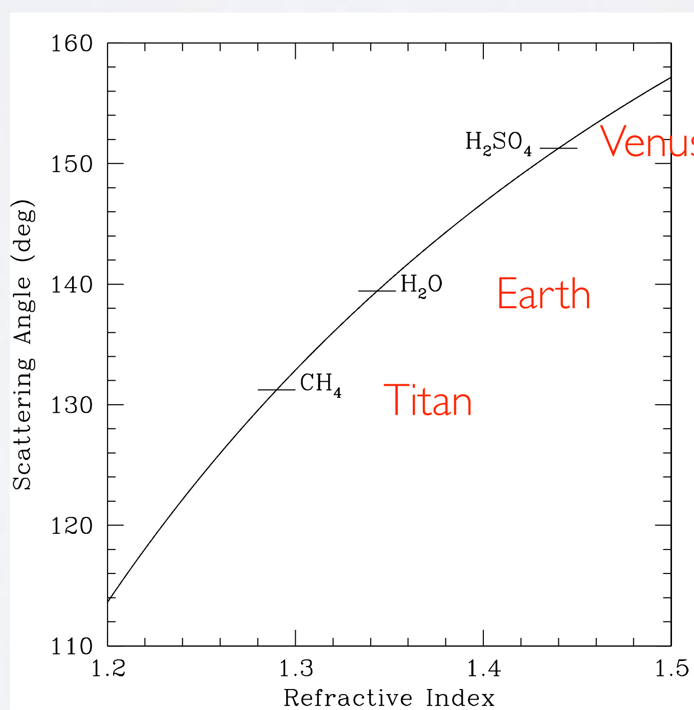


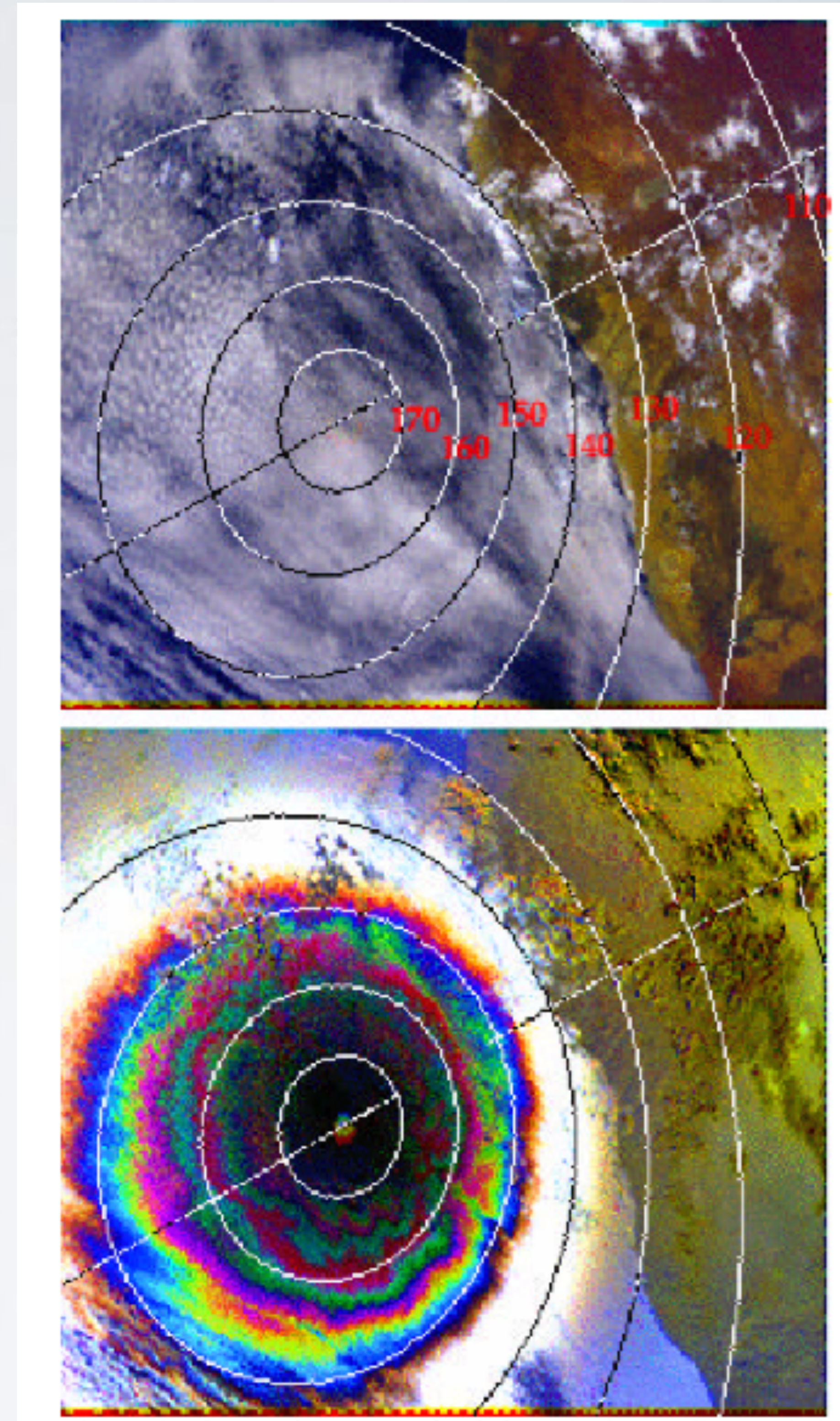
T. Wilson et al. Nature 525, 234-238 (2015):
A Marine biogenic source of atmospheric ice-nucleating particles

Polarimetric Signatures of Planet Earth

rainbow polarization

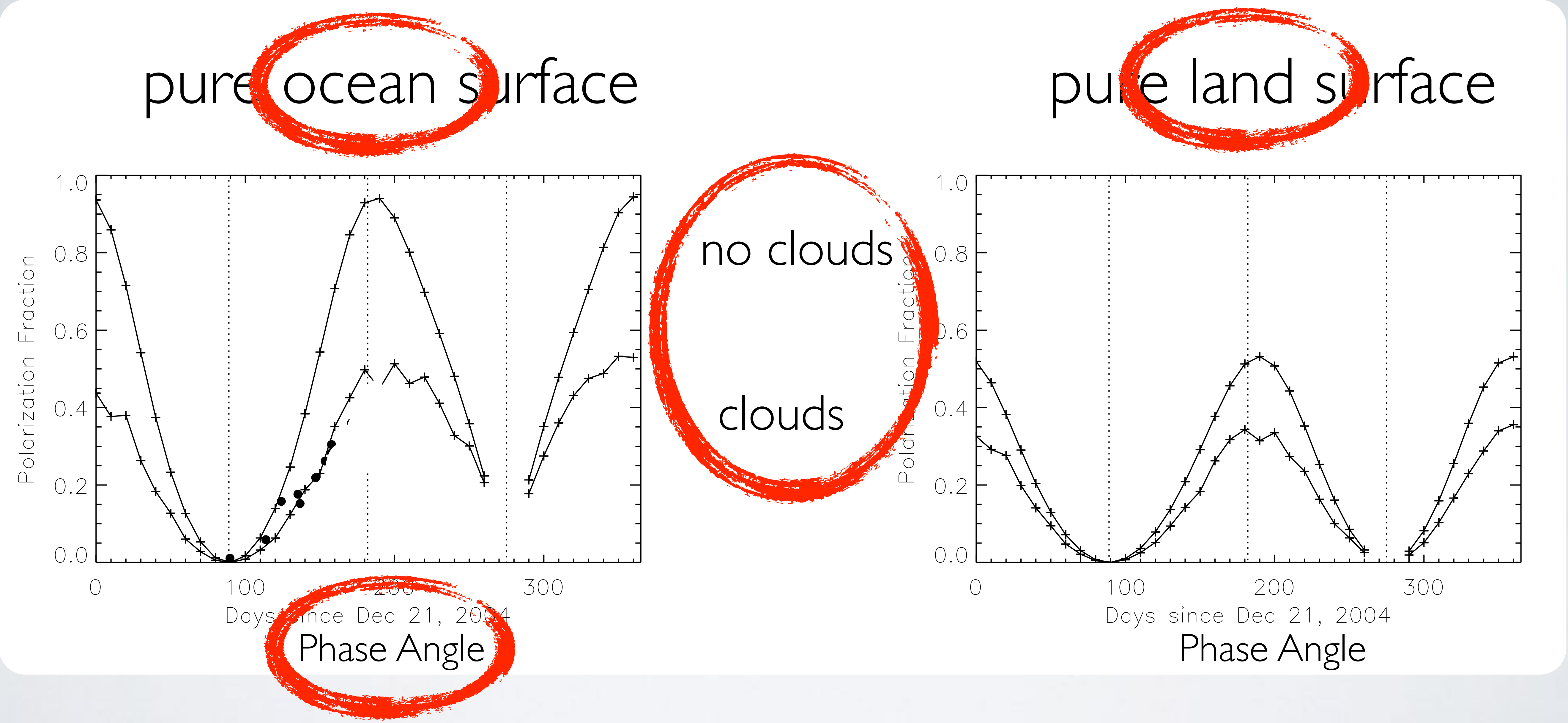






Hansen, J. E. & Hovenier, J. W. Interpretation of the polarization of Venus. *Journal of Atmospheric Science* **31**, 1137–1160 (1974).
Bréon, F. M. & Goloub, P. Cloud droplet effective radius from spaceborne polarization measurements. *Geophysical research letters* **25**, 1879–1882 (1998).
Bailey, J. Rainbows, Polarization, and the Search for Habitable Planets. *Astrobiology* **7**, 320–332 (2007).

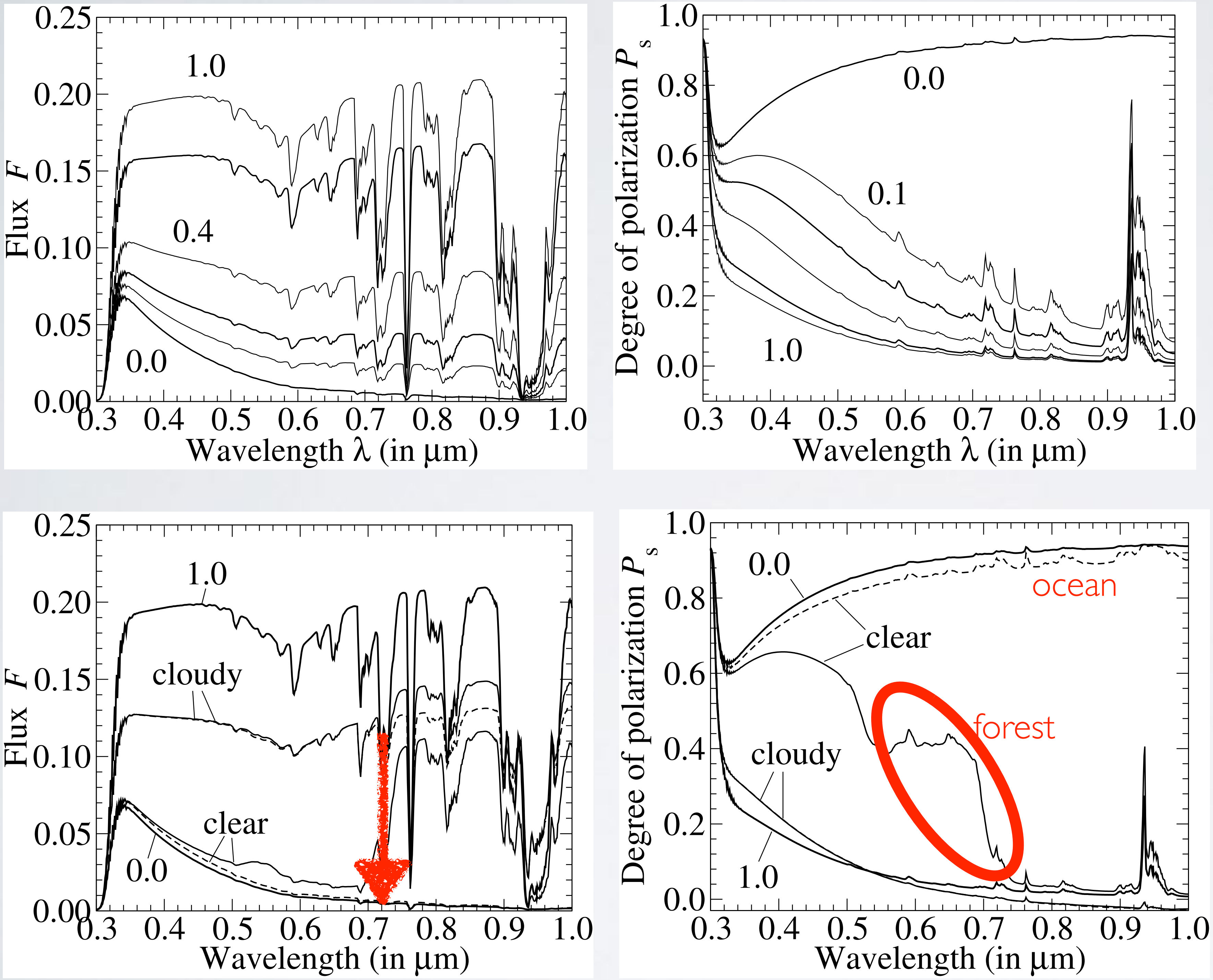
Polarimetric Signatures of Planet Earth



McCullough, P. R. Models of Polarized Light from Oceans and Atmospheres of Earth-like Extrasolar Planets. *arXiv* **astro-ph**, (2006).

Williams, D. M. & Gaidos, E. Detecting the glint of starlight on the oceans of distant planets. *Icarus* **195**, 927–937 (2008).

Modelling Earth's Polarization



VRT calc. include

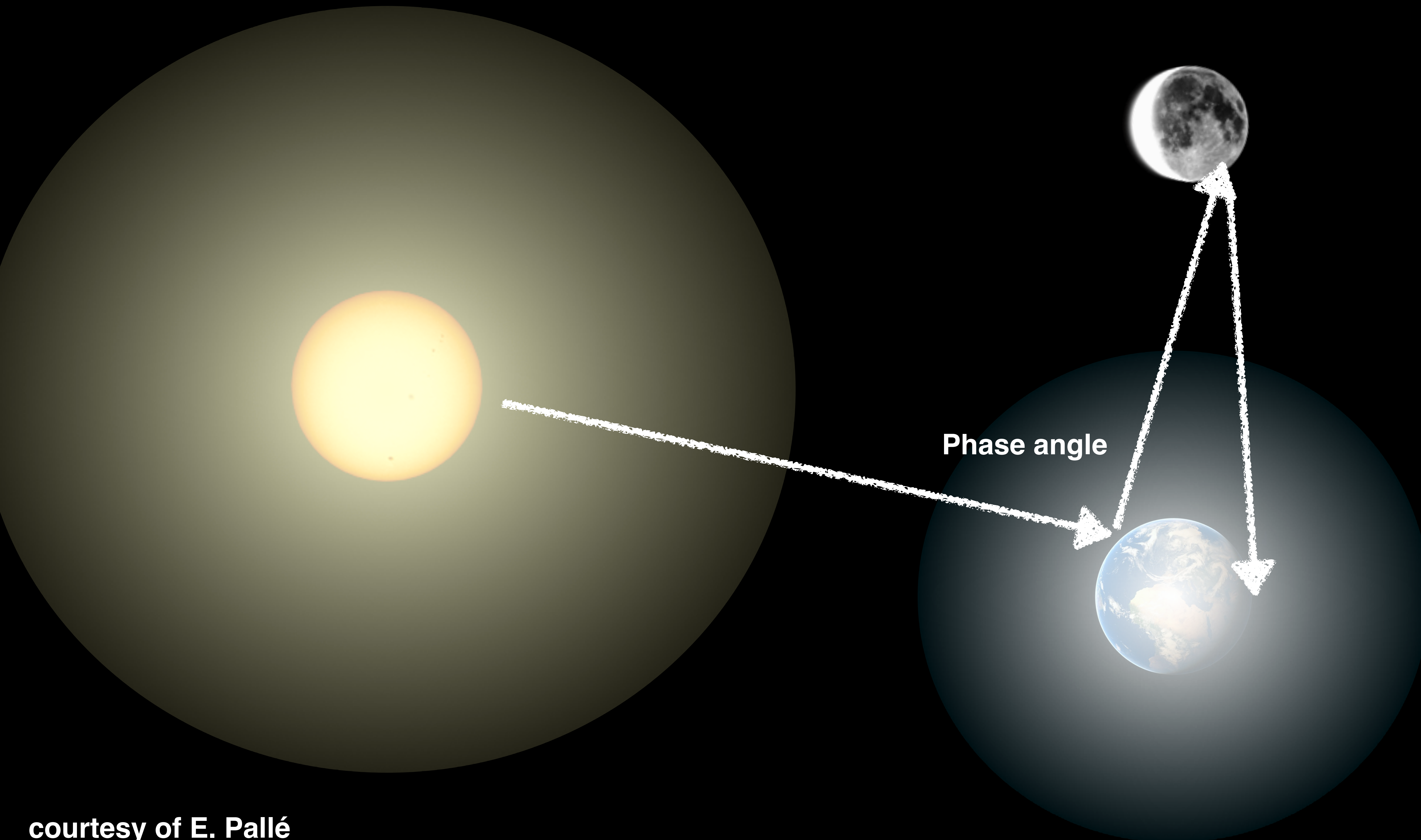
atmosphere
geometry
surfaces

missing

inhomogenities
realistic clouds
aerosols/haze
realistic surfaces

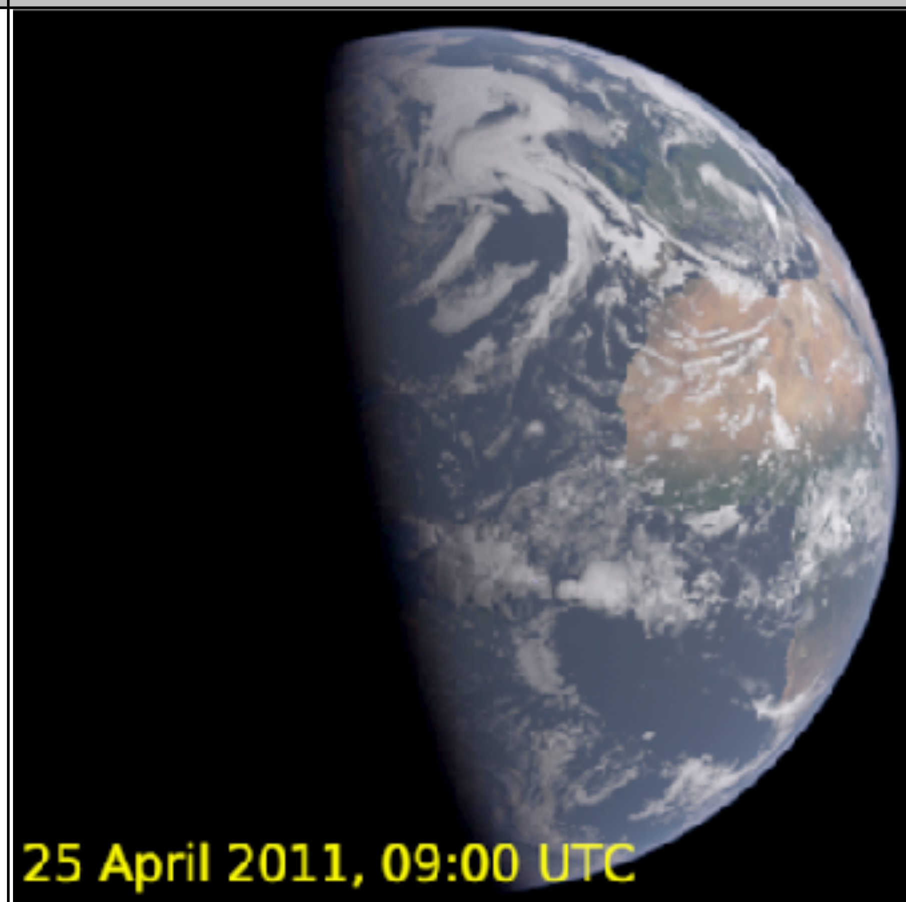
Stam, D. M. Spectropolarimetric signatures of Earth-like extrasolar planets. *A&A* **482**, 989–1007 (2008)

Earthshine



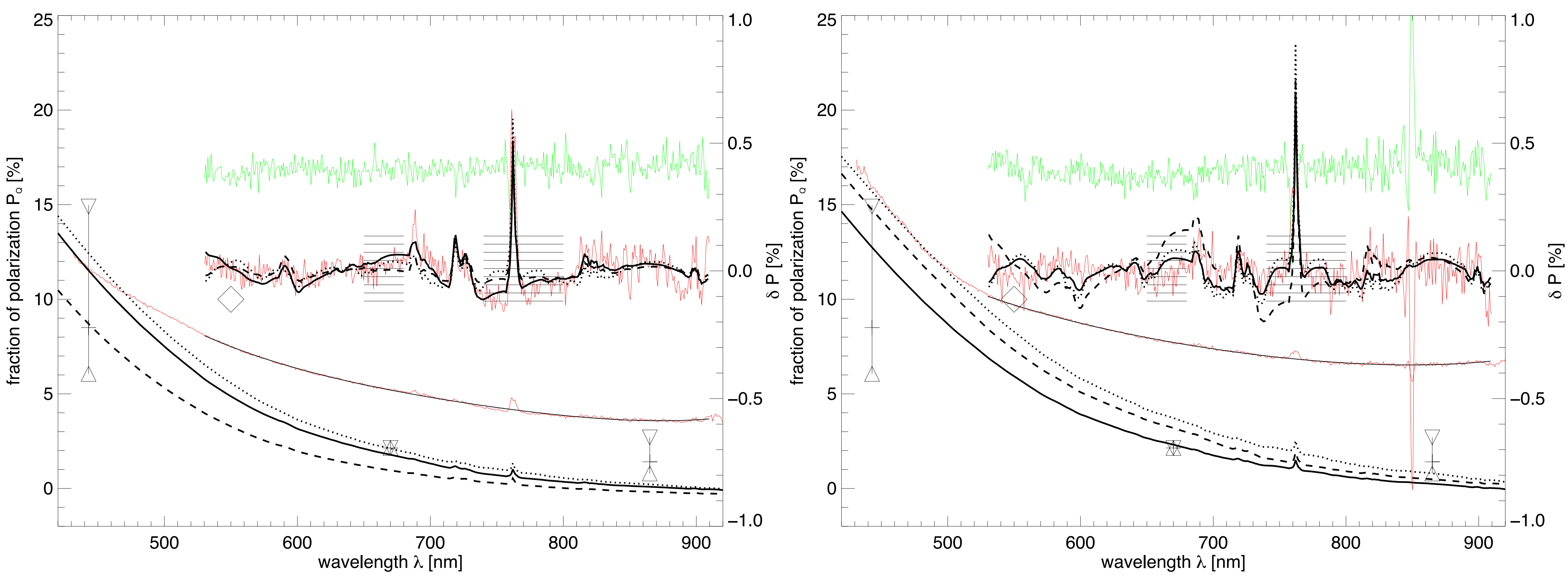
courtesy of E. Pallé

Spectropolarimetry of ES:

Observing Date	25-Apr-2011:UT09	10-Jun-2011:UT01
View of Earth as seen from the Moon		
Sun-Earth-Moon phase	87 deg	102 deg
ocean fraction in Earthshine	18%	46%
vegetation fraction in Earthshine	7%	3%
tundra, shrub, ice and desert fraction in Earthshine	3%	1%
total cloud fraction in Earthshine	72%	50%
cloud fraction t > 6	42%	27%

line vers. continuum

25-Apr-2011:UT09 10-Jun-2011:UT01

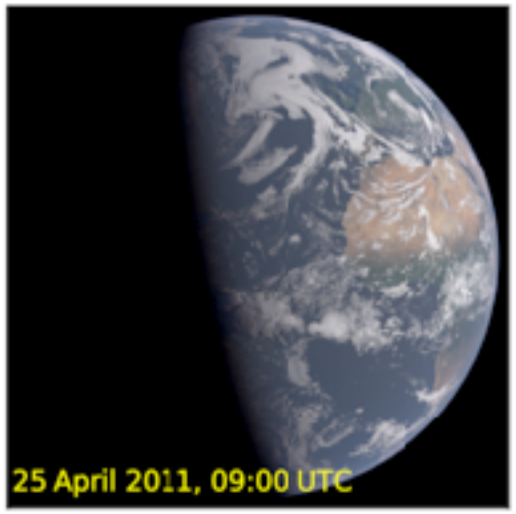


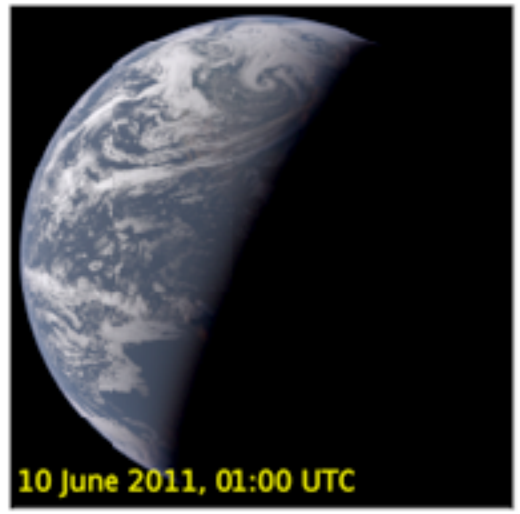
D. Stams model spectra (3nm resolution) agree qualitatively with the measurements (1nm): O2A strength, water, NDVI.

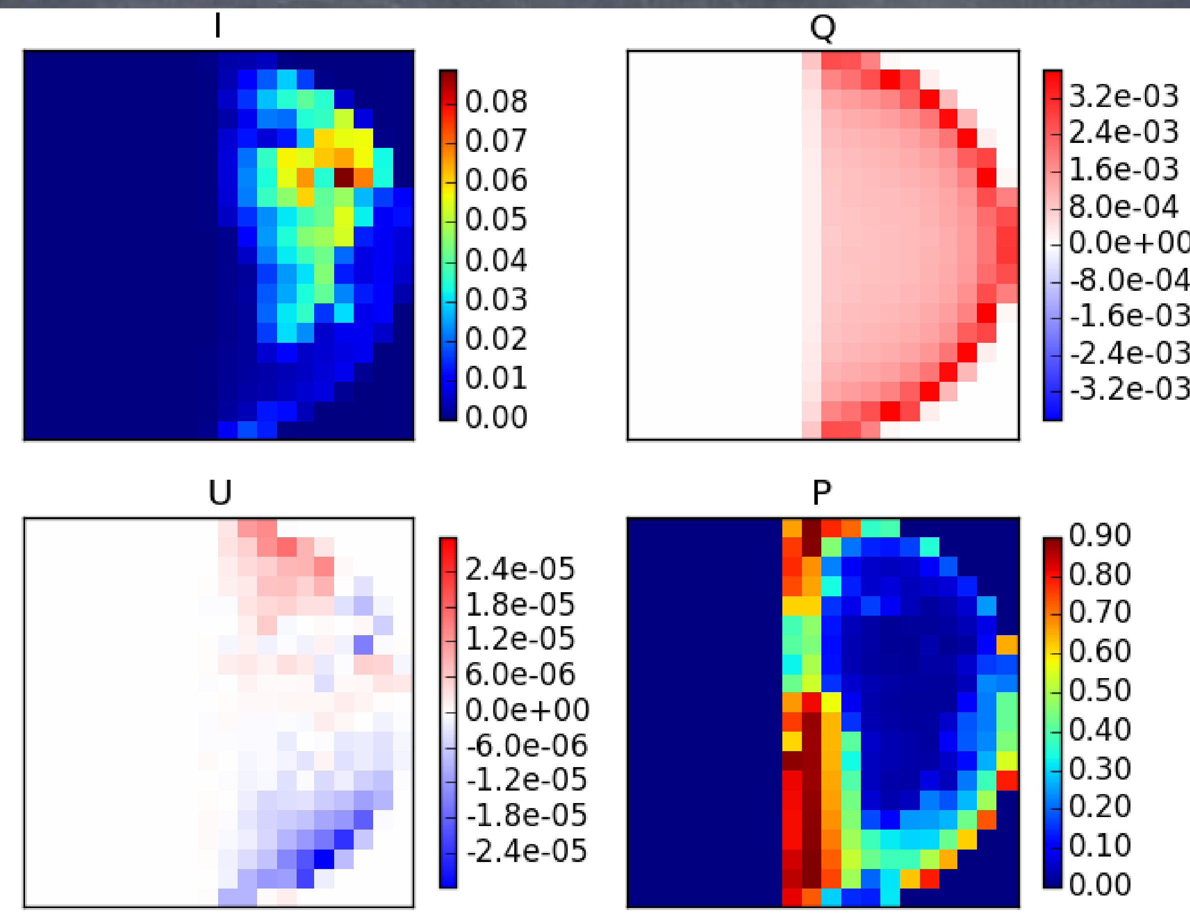
Sterzik, M. F., Bagnulo, S. & Pallé, E. Biosignatures as revealed by spectropolarimetry of Earthshine. *Nature* **483**, 64–66 (2012).

MYSTIC 3D-vec. rad. transfer

w/ C. Emde (Monte Carlo code for the phYSically correct Tracing of photons In Cloudy atmospheres)

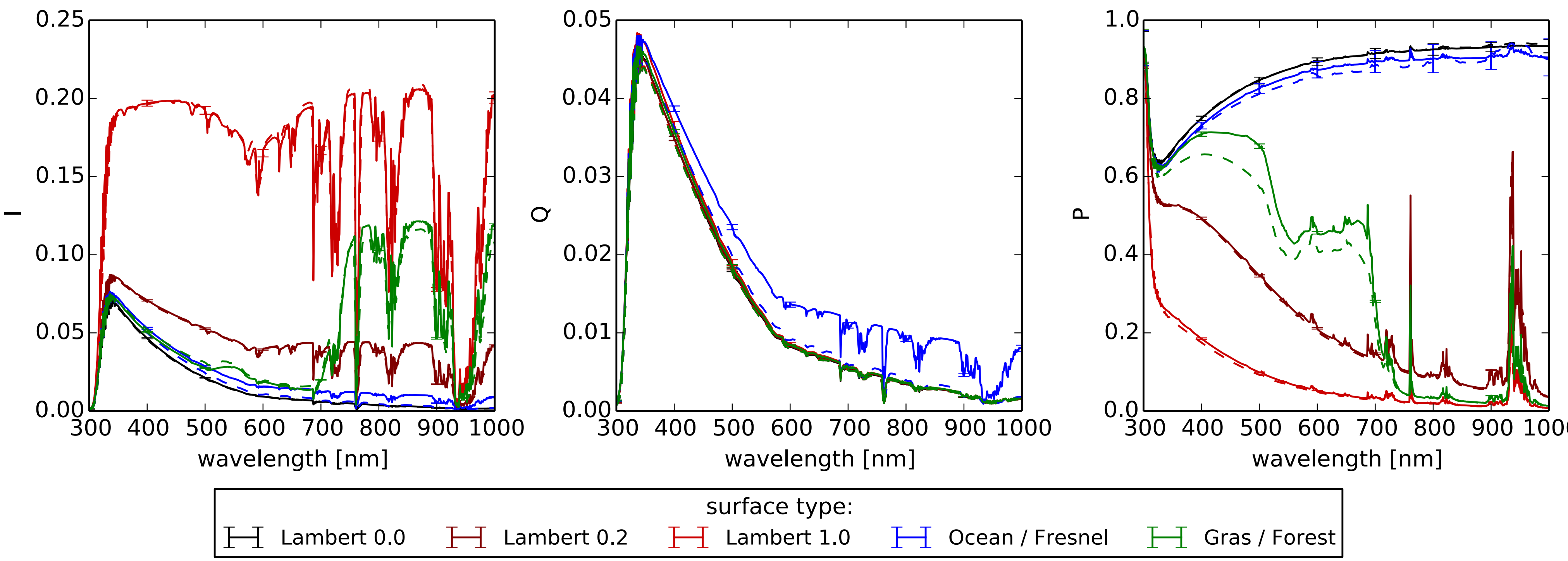




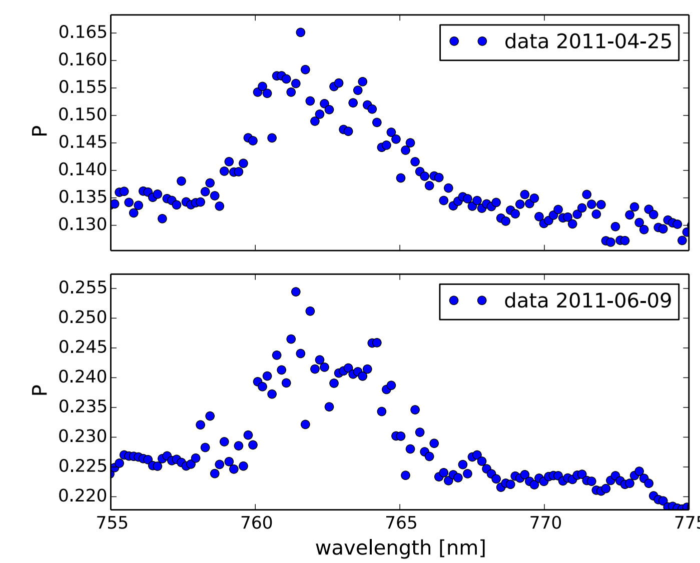


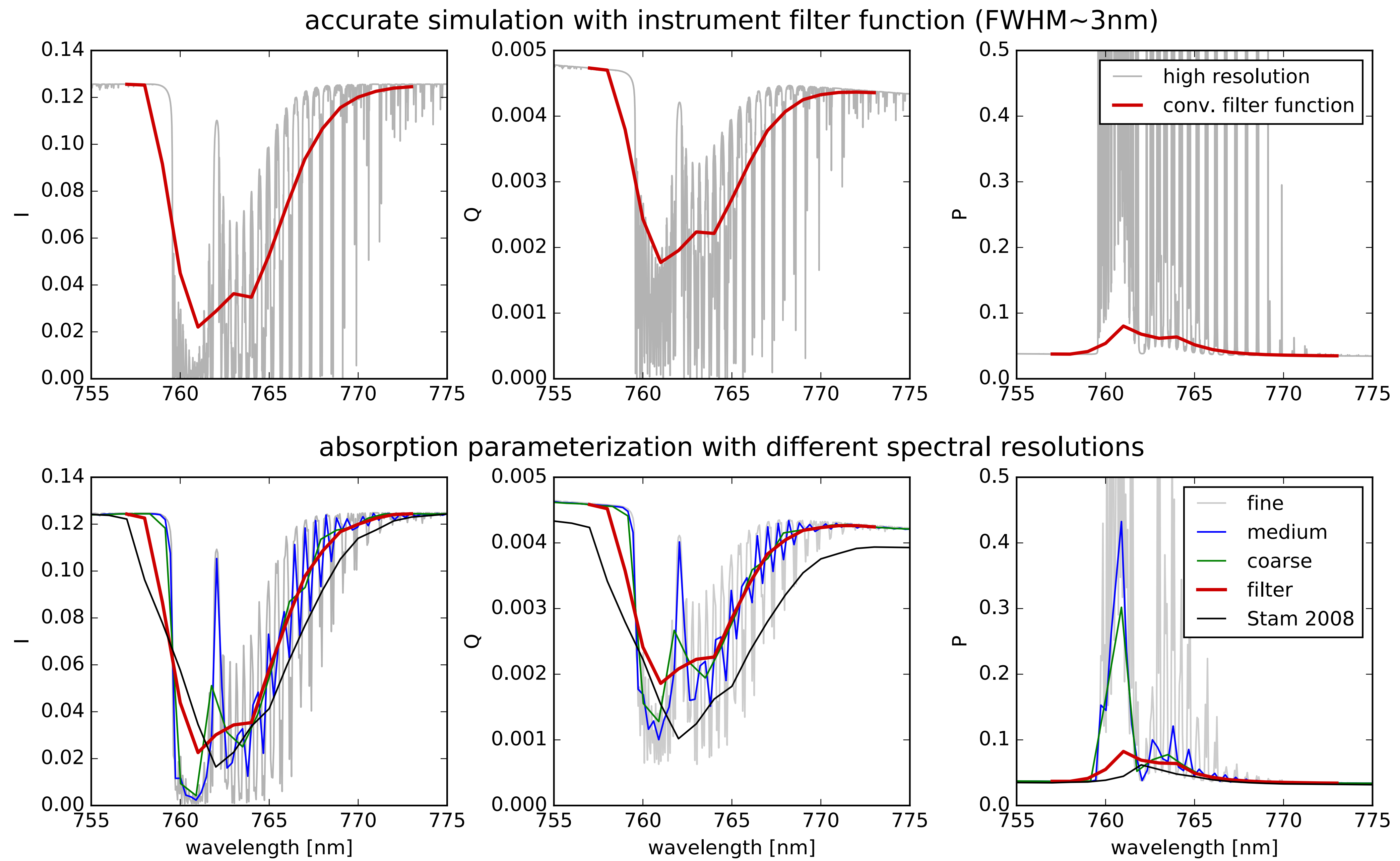
Emde, C., Buras, R., Mayer, B. & Blumthaler, M. The impact of aerosols on polarized sky radiance: **model development, validation, and applications**. *Atmos. Chem. Phys. 10*, 383–396–396 (2010).

Emde, C., Buras, R. & Mayer, B. An efficient method to compute **high spectral resolution** polarized solar radiances using the **Monte Carlo** approach. *Journal of Quantitative Spectroscopy and Radiative Transfer* **112,** 1622–1631 (2011).

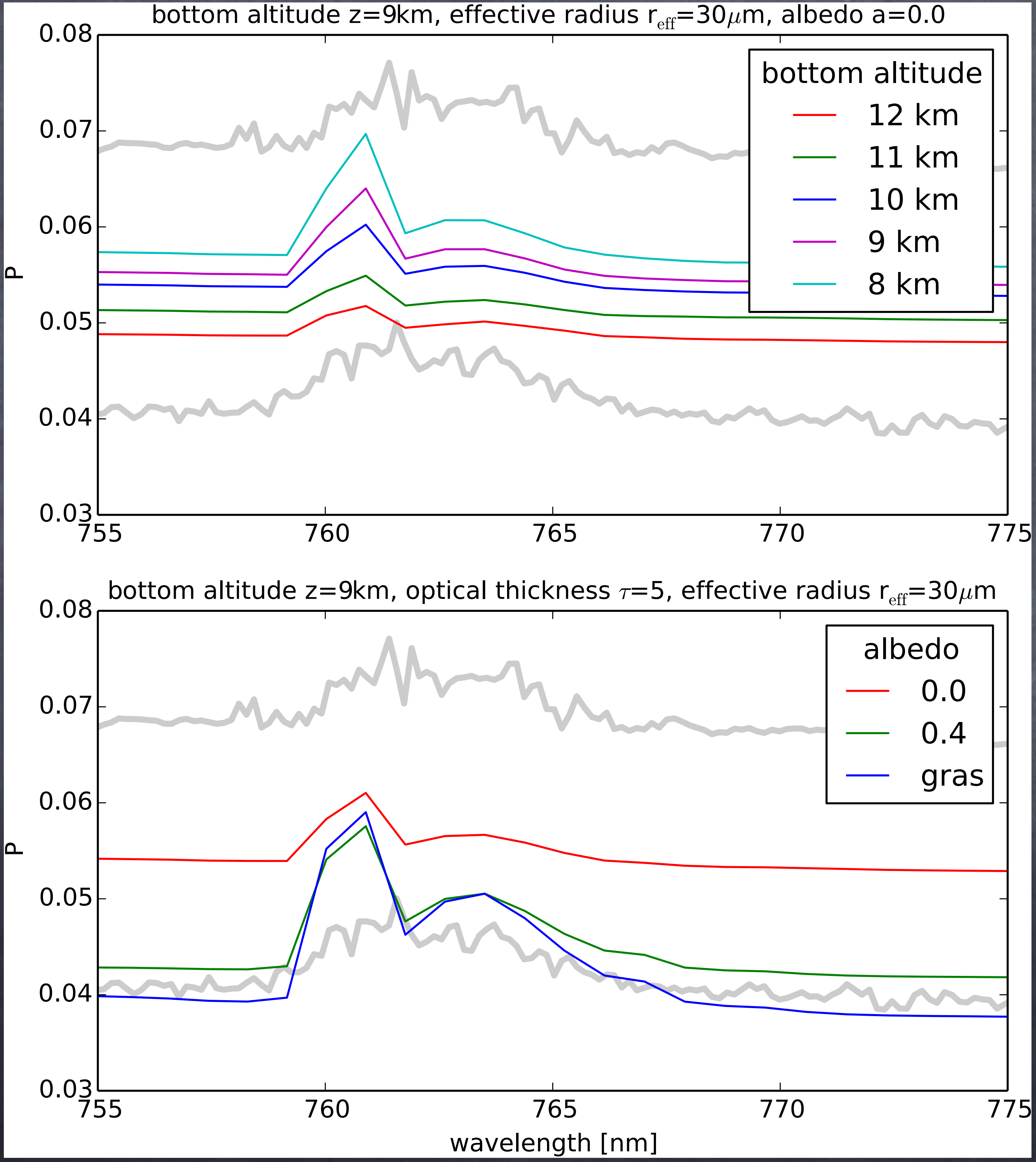


We'd like high spectral resolution



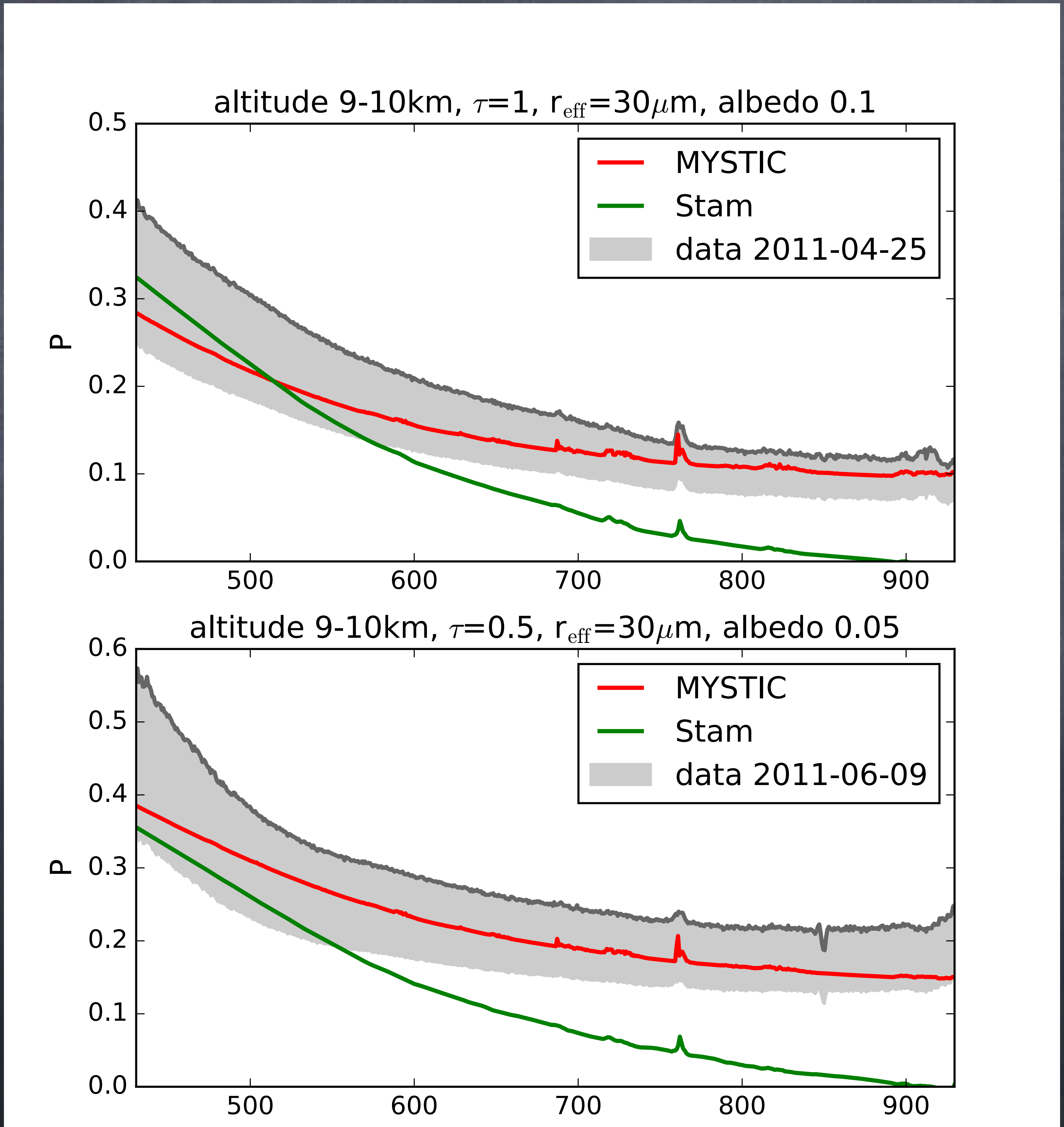


Sensitivity of high altitude clouds

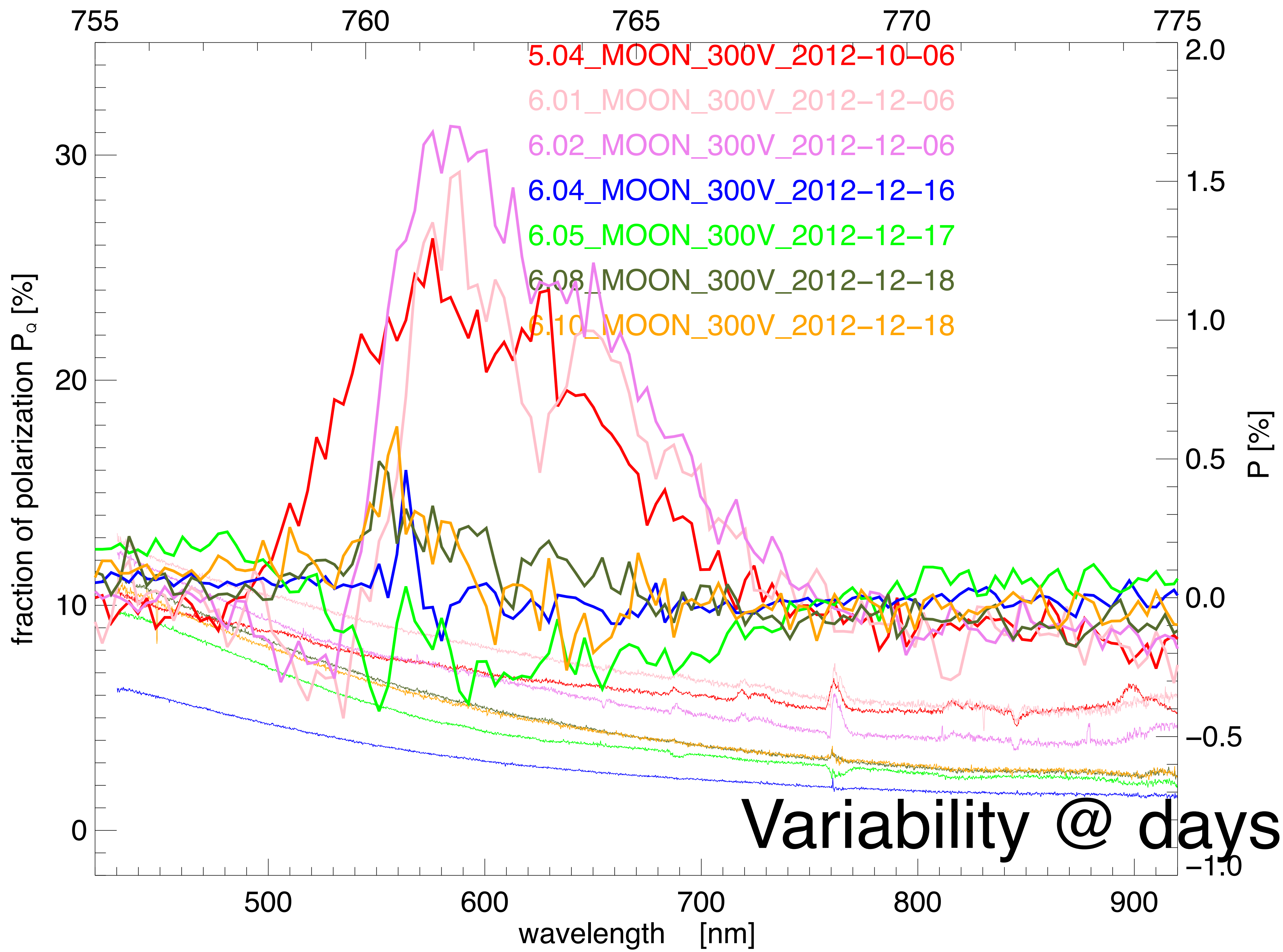


Emde, C., Buras, R., Sterzik, M.. & Bagnulo, S. Influence of aerosols, water and ice clouds on polarisation spectra of Earthshine. *A&A ref.* (2017).

ES modelling vers.2

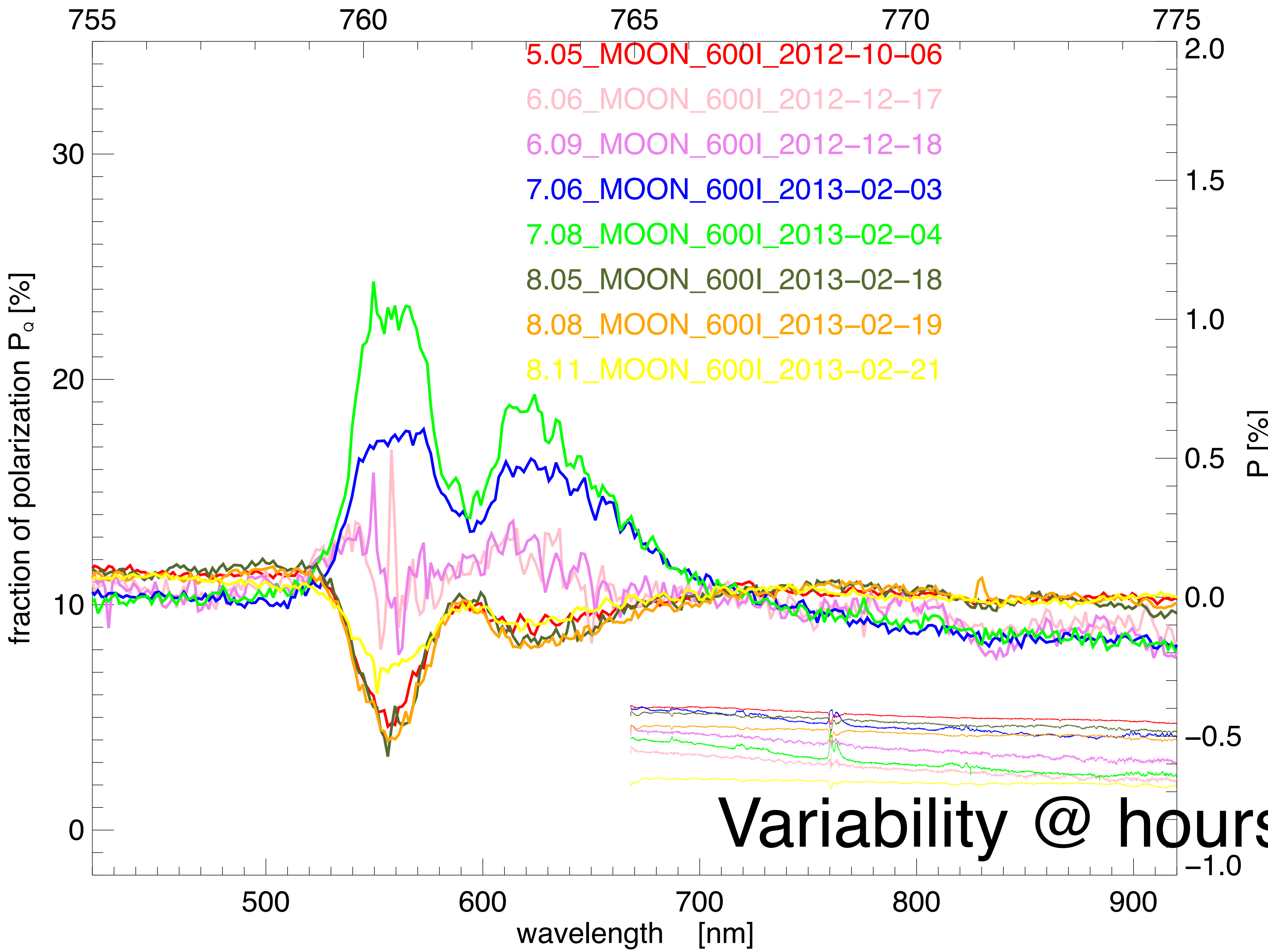


Earthshine O2-A observed



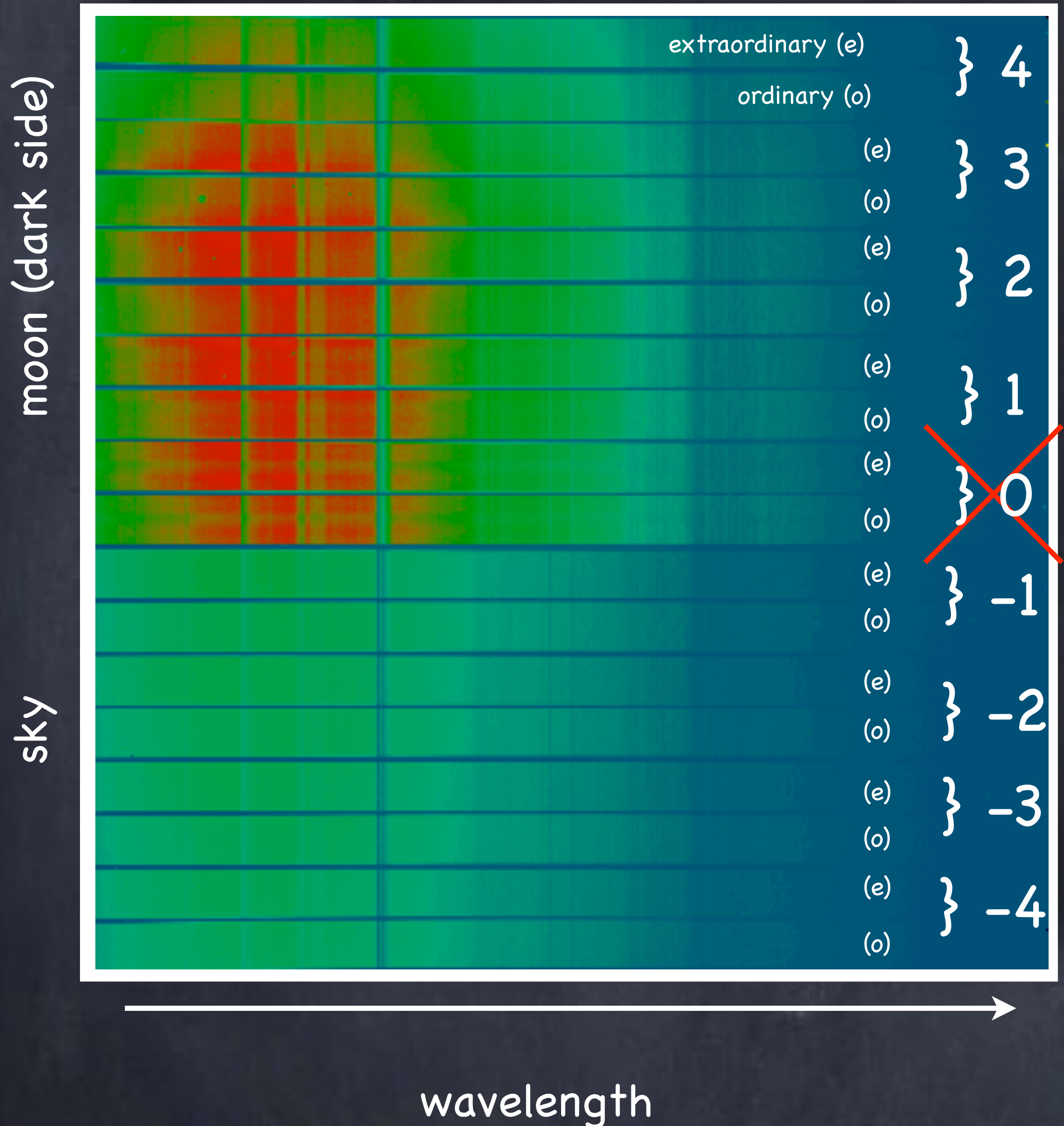
Variability @ days?

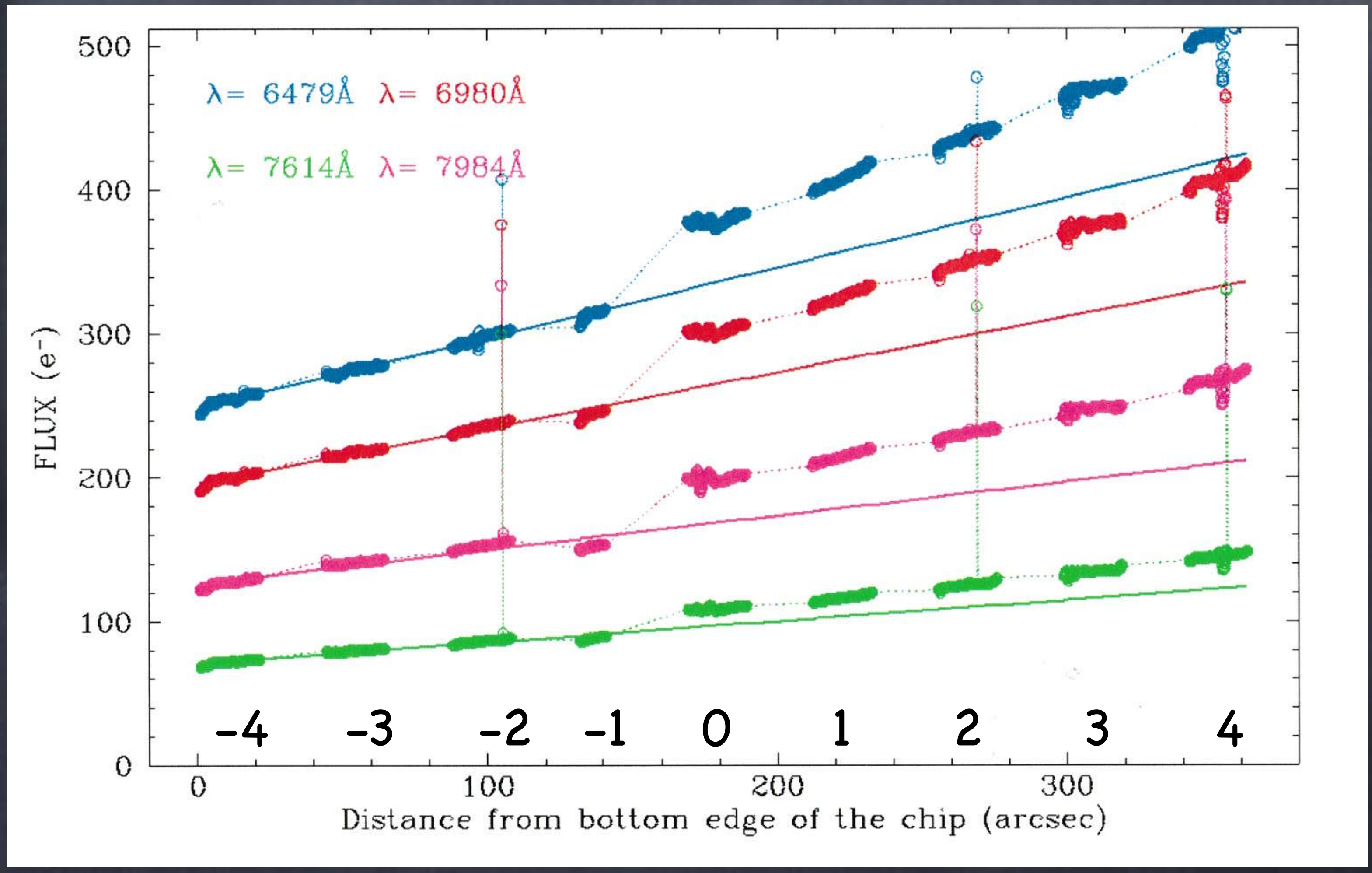
Earthshine O2-A observed



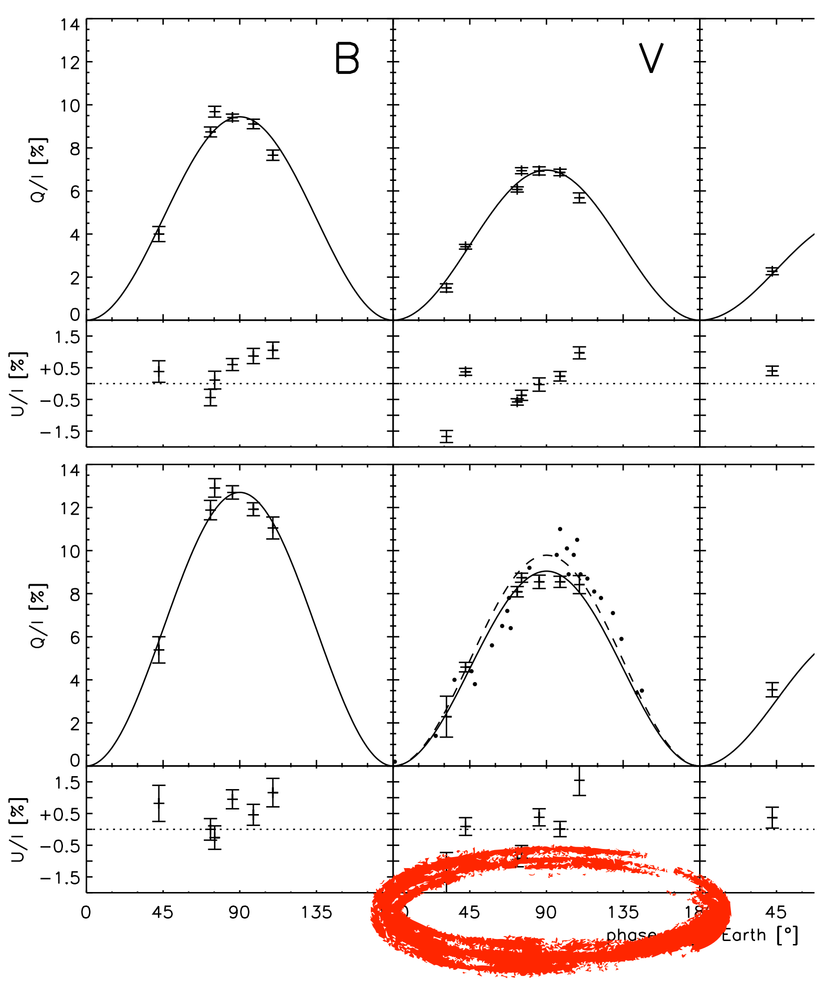
Variability @ hours??

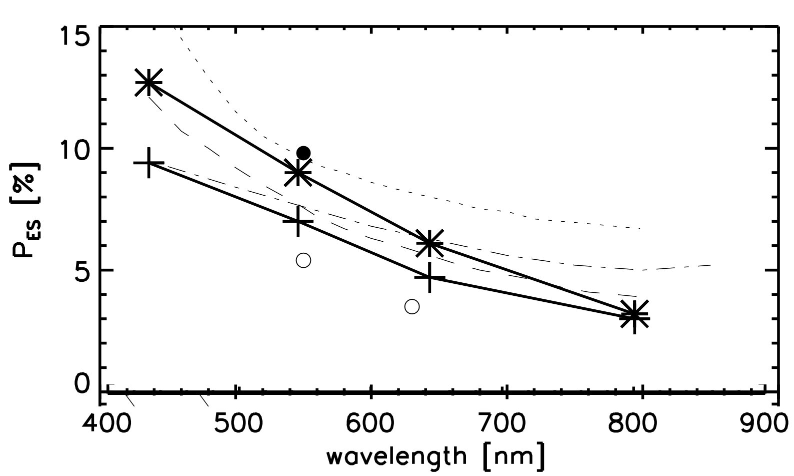
Signal and Background around the Lunar Limb



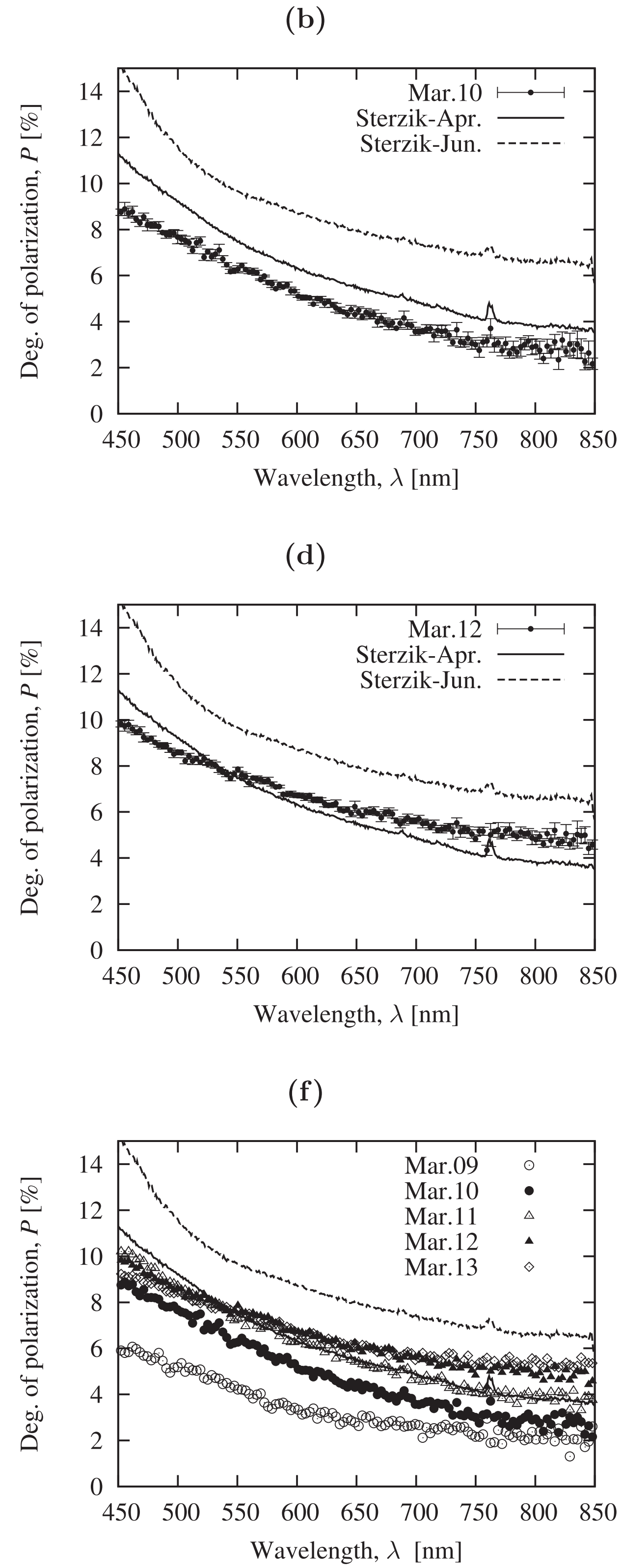


More (Spectro-)Polarimetry of ES

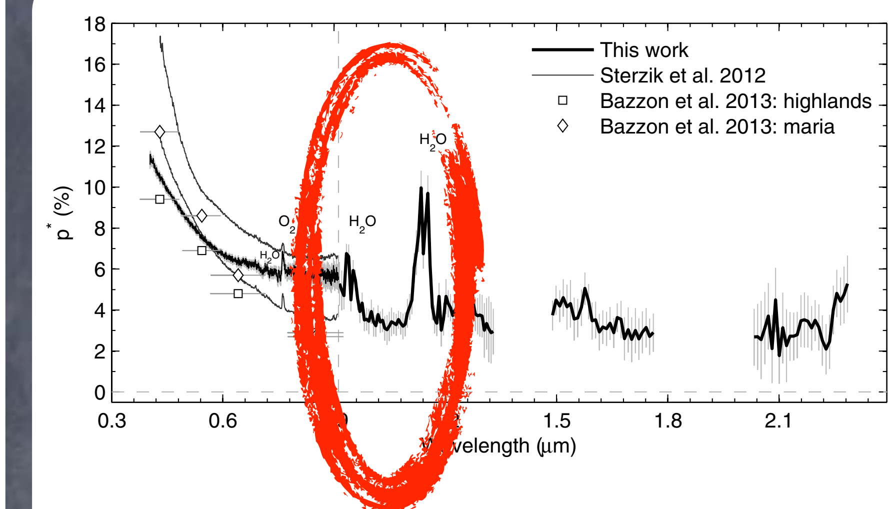




Bazzon, A., Schmid, H. M. & Gisler, D. Measurement of the earthshine polarization in the B, V, R, and I band as **function of phase**. *arXiv* astro-ph.EP, (2013).



Takahashi, J. *et al.* **Phase Variation** of Earthshine Polarization Spectra. *Publications of the Astronomical Society of Japan* **65,** 38 (2013).



Miles-Páez, P. A., Pallé, E. & Zapatero Osorio, M. R. Simultaneous optical and **near-infrared** linear spectropolarimetry of the earthshine. A&A 562, L5 (2014).

GEOPHYSICAL RESEARCH LETTERS, VOL. 26, NO.5, PAGES 591-594, MARCH 1, 1999

Spectral fine-structure in the polarisation of skylight

I. Aben[1], F. Helderman[1], D.M. Stam[2,3,4], and P. Stammes[3]

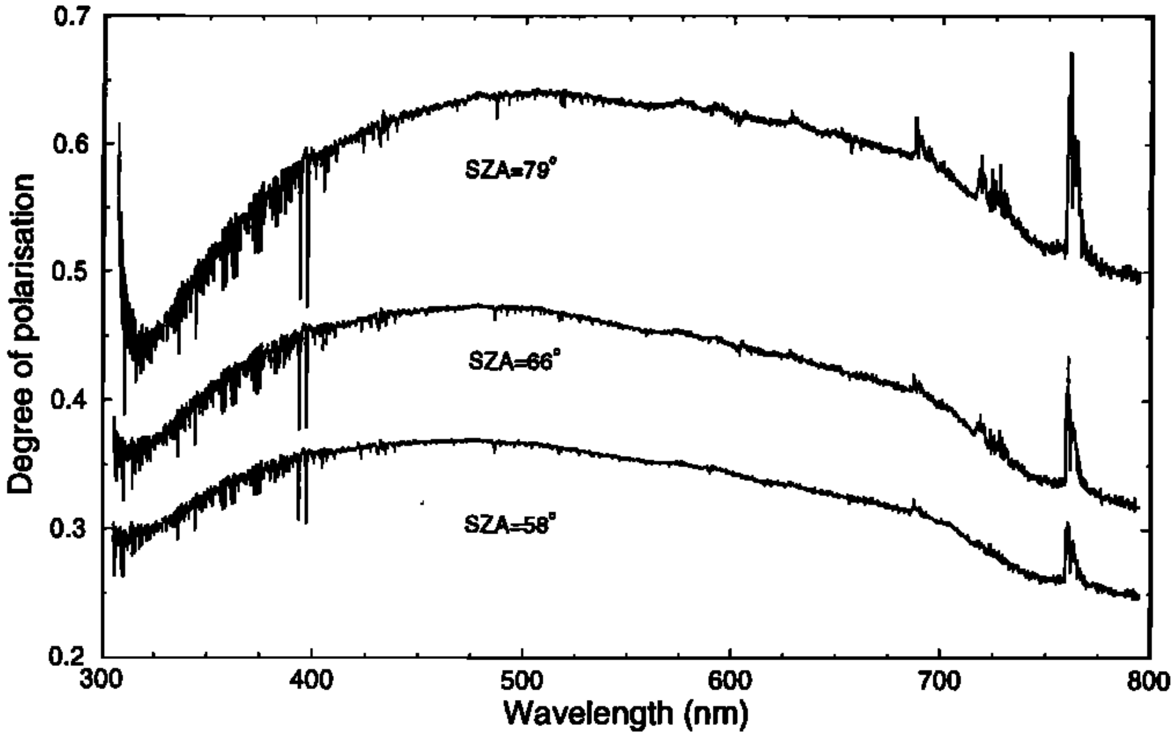


Figure 1. The degree of linear polarisation of the cloud-free zenith sky as a function of wavelength from 305 to 794 nm, for three values of the solar zenith angle (SZA), as measured at SRON, Utrecht, The Netherlands (52.1°N, 5.2°E) on the morning of April, 7, 1997. Superimposed on the broad-band continuum, spectral fine-structure in the polarisation is observed.

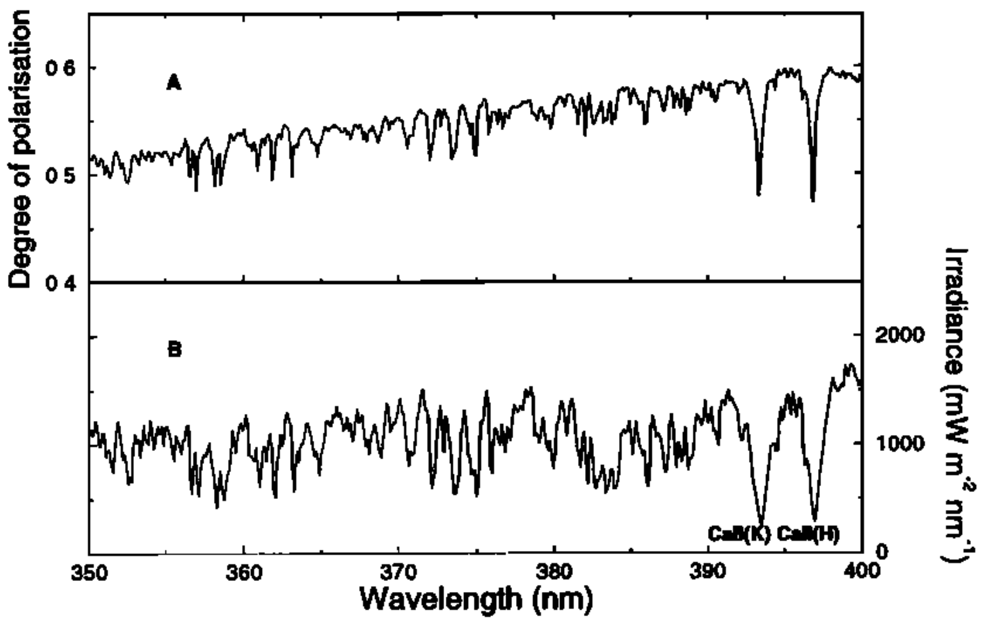
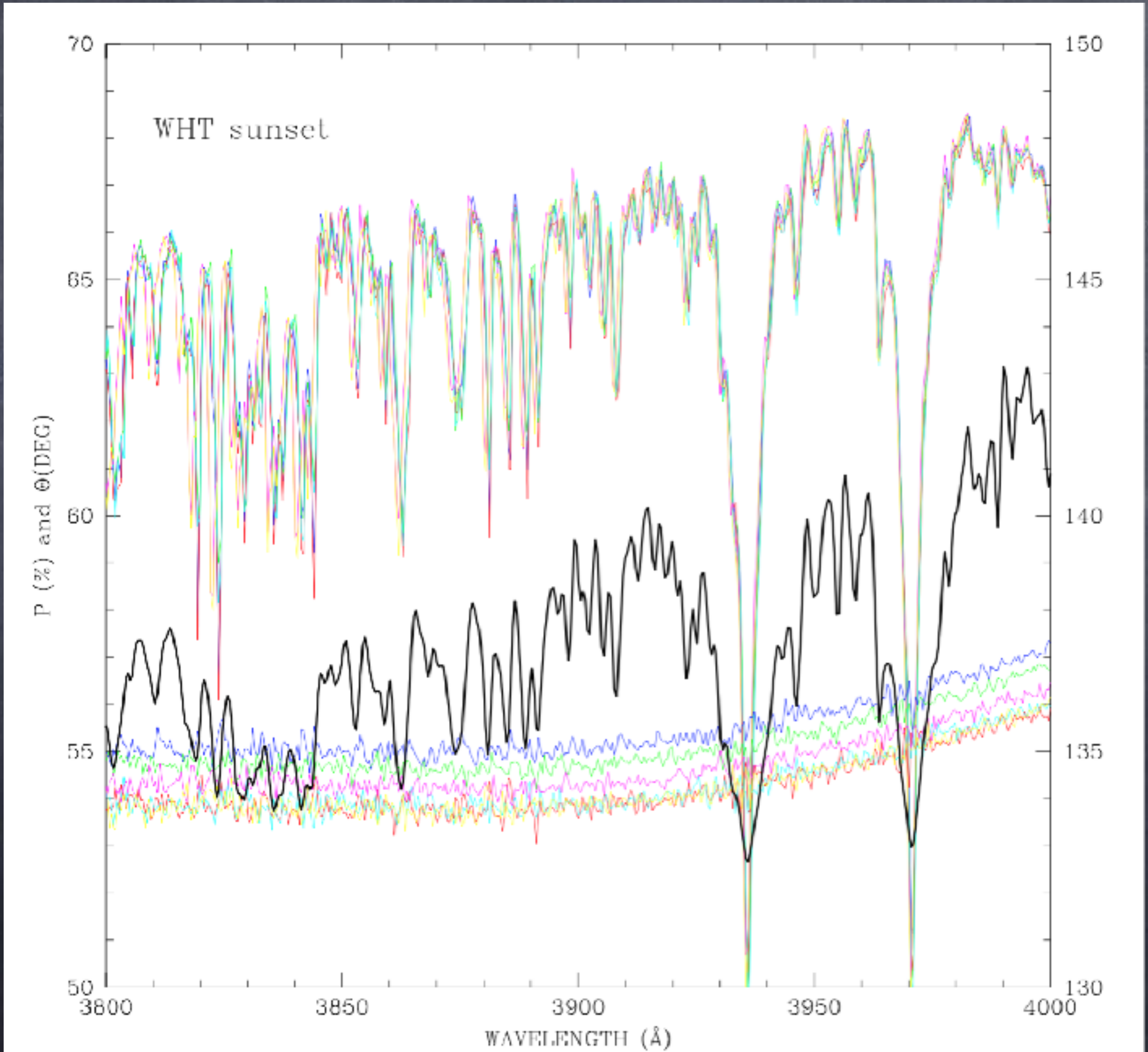


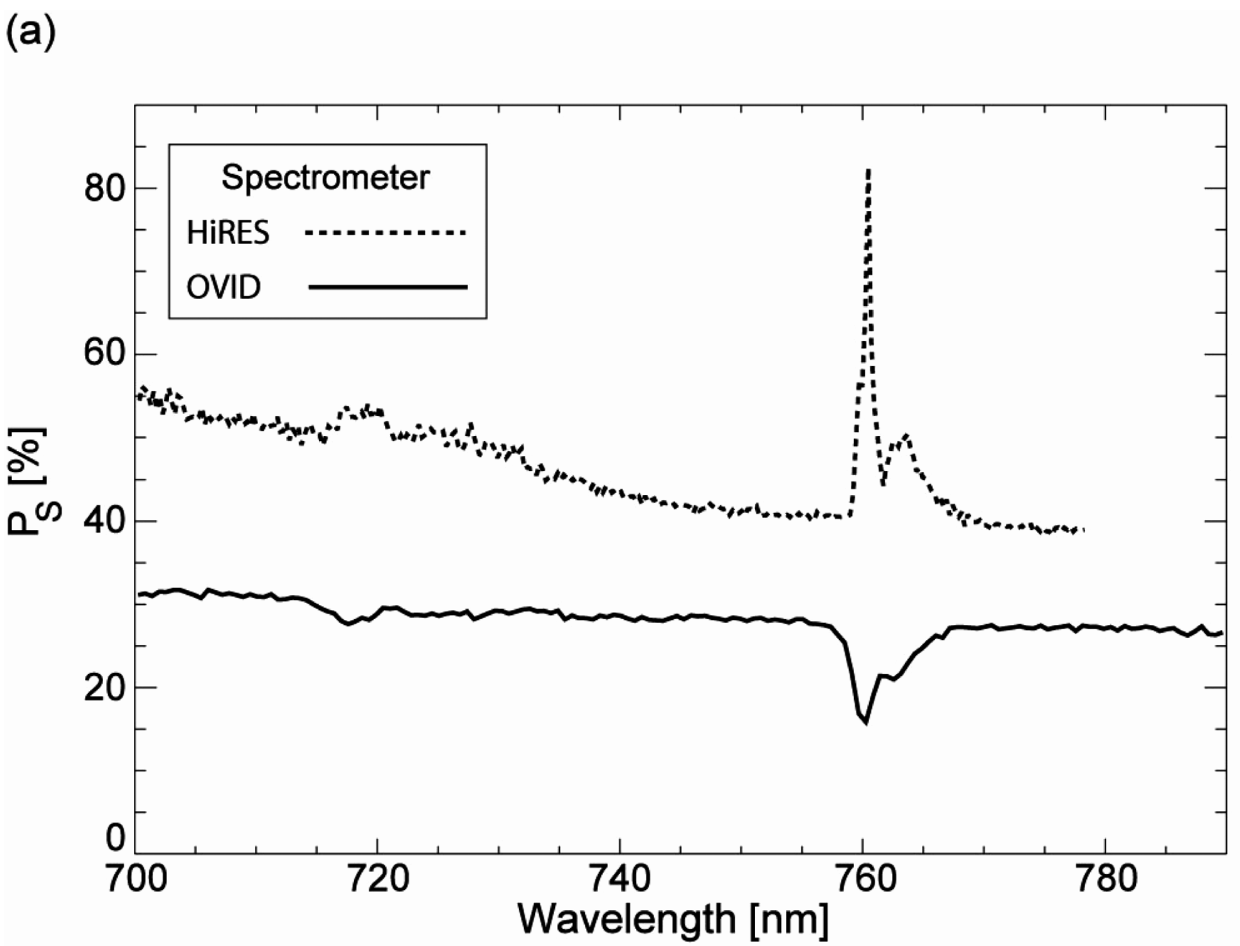
Figure 3. The UV part of the zenith sky polarisation spectrum for SZA = 79°is shown in more detail (top). The spectral fine-structure in the measured polarisation coincides closely with the Fraunhofer lines in the extraterrestrial solar irradiance spectrum (bottom). The latter has been measured on April, 7, 1997, by GOME on ERS-2. Even the smallest spectral features in the polarisation coincide with Fraunhofer lines, which demonstrates the precision ($\sim 10^{-3}$) of the measurements.

Spectropolarimetry of our Sky



Polarization of skylight in the O_2A band: effects of aerosol properties

Eyk Boesche,[1,*] Piet Stammes,[2,4] Réne Preusker,[1] Ralf Bennartz,[3,5]
Wouter Knap,[2] and Juergen Fischer[1]



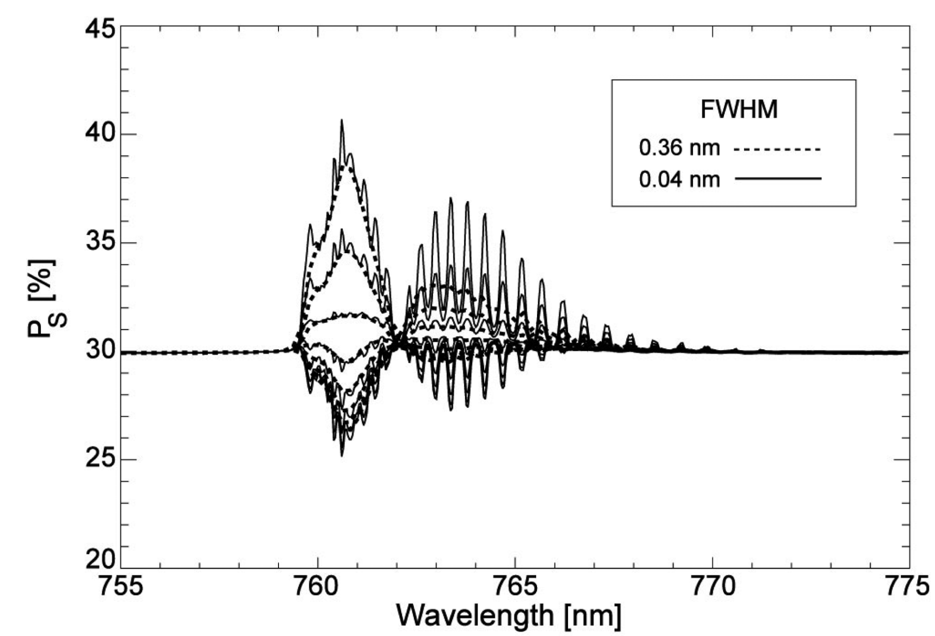
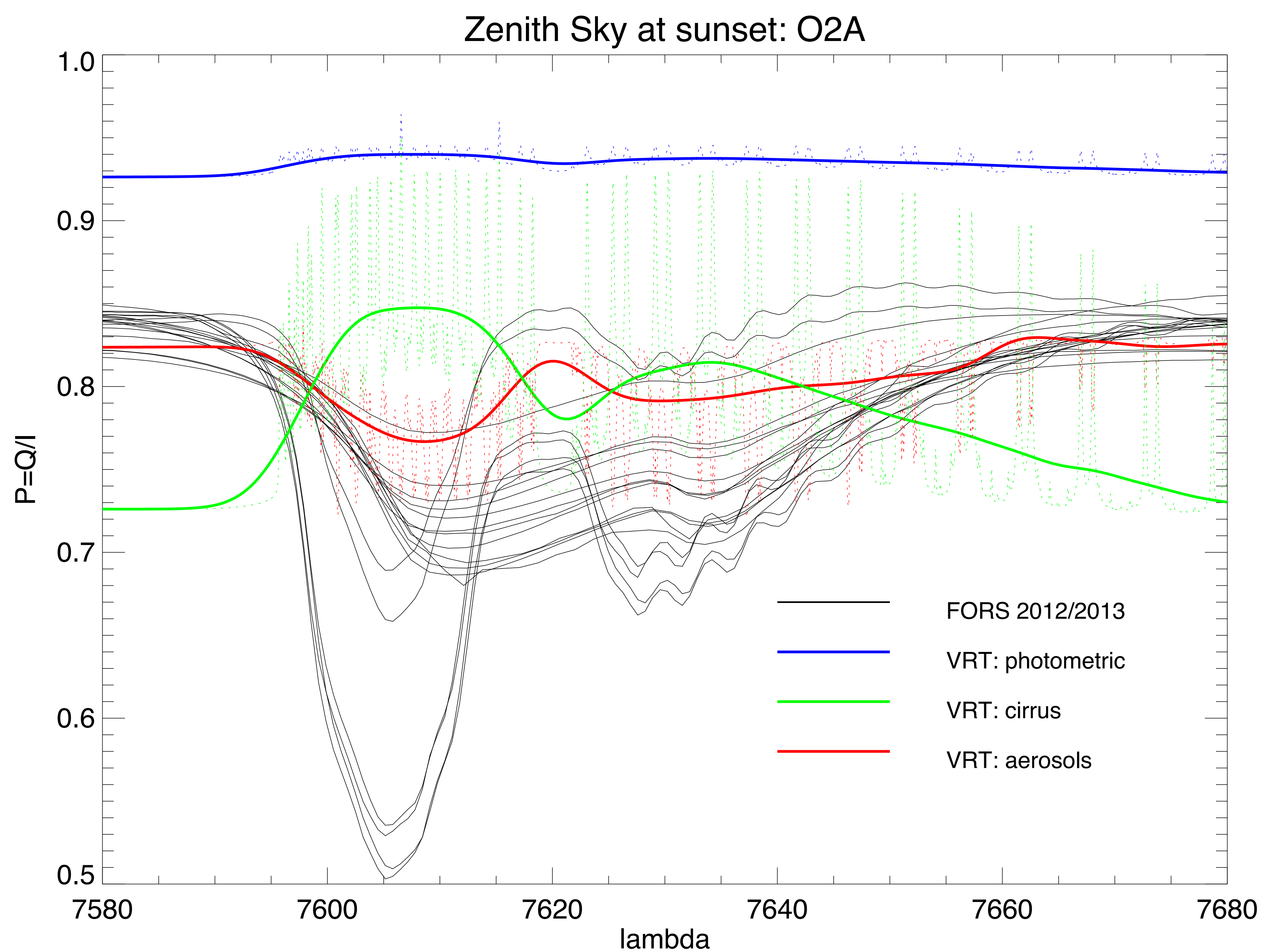
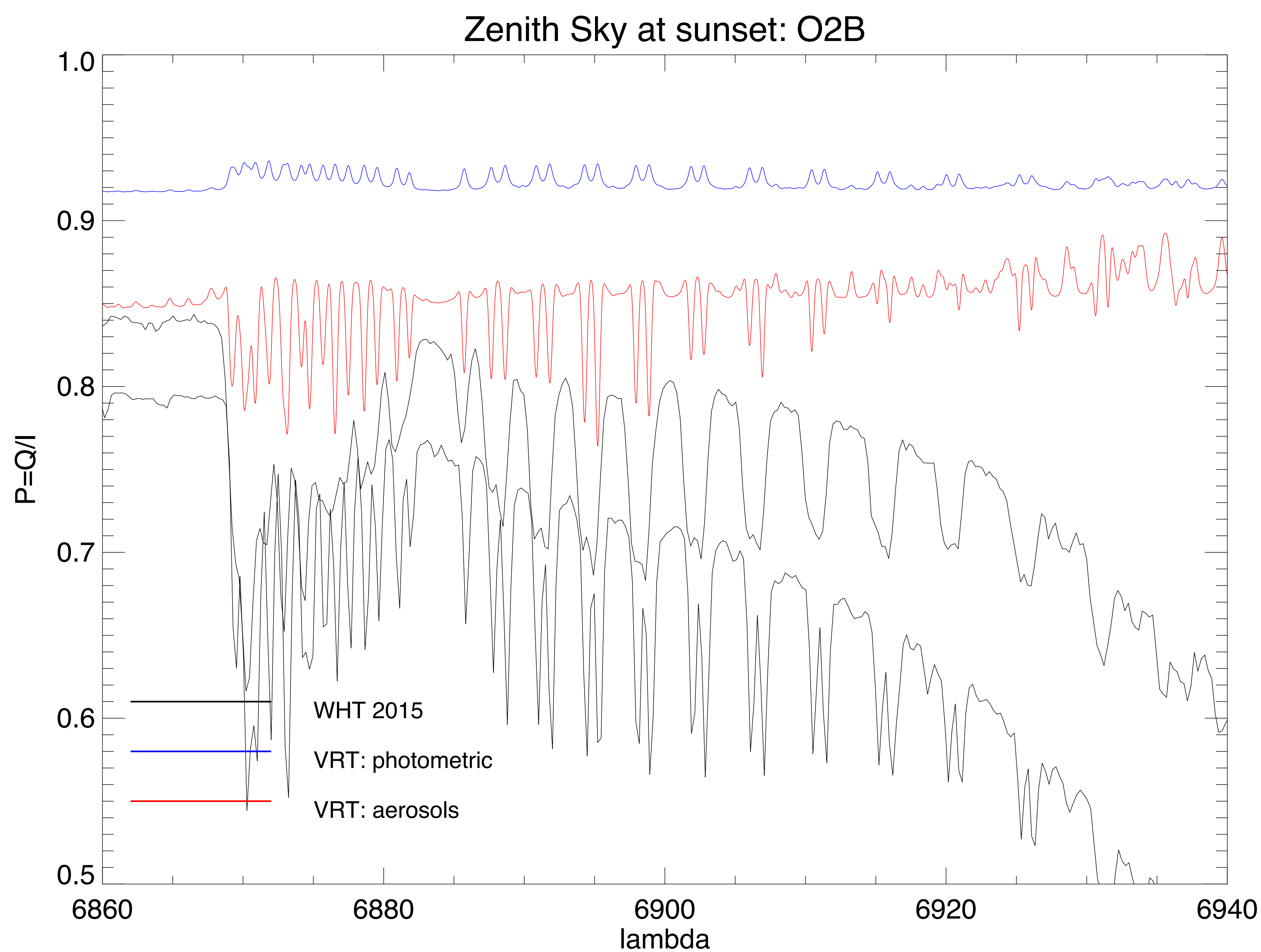


Fig. 11. Degree of linear polarization of zenith skylight as a function of wavelength at a solar zenith angle of $\theta_0 = 65°$ for two different spectral response functions and different altitudes of the elevated scattering layer. The boundary layer comprises Aerosol_1 and optical thickness of $\tau_{BL} = 0.048$ and the elevated layer comprises scatterer C_1 with $\tau_{EL} = 0.100$. The elevated layer is shifted through the atmosphere from 2 to 16 km in steps of two kilometers, resulting in a decrease of P_b with increasing altitude of the elevated layer.

Spectropolarimetry of our Sky



Spectropolarimetry of our Sky



Proposal: SpecPols of Zenith Sky

- use FORS2pol and HARPSpol @ high spectral resolution
- monitoring of sunset sky-flats
- **retrieve aerosol and cirrus content, composition, and height distribution with VRT model**
- timescale of variability (stability)
- correlate with extinction
- correlate with local (mining) and global (vulcano) effects
- validate retrieval code for the local (zenith) patch
- apply to Earthshine skybackground/global retrieval