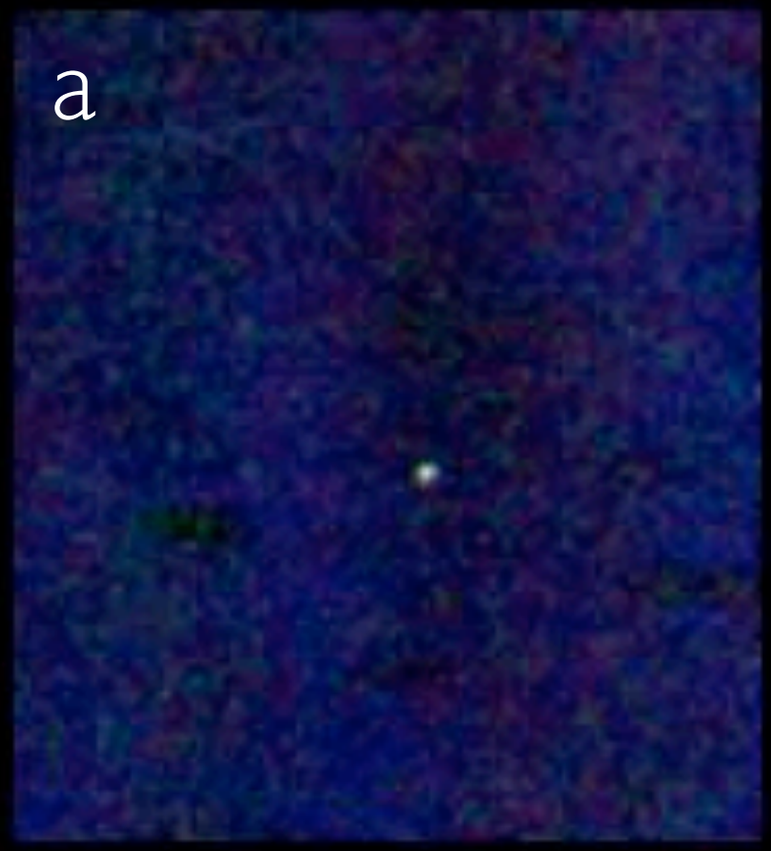
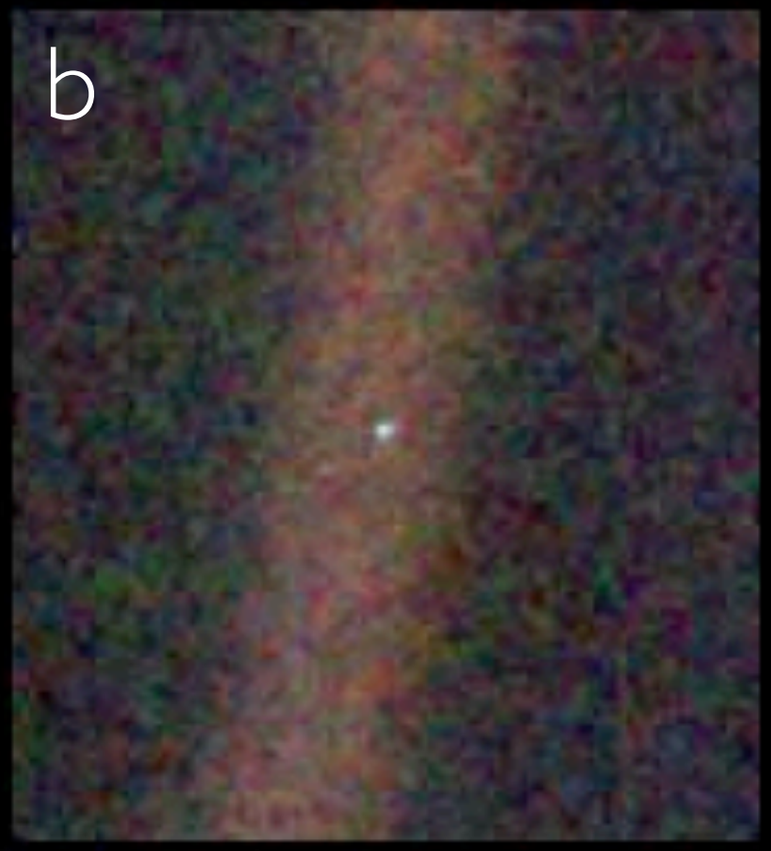
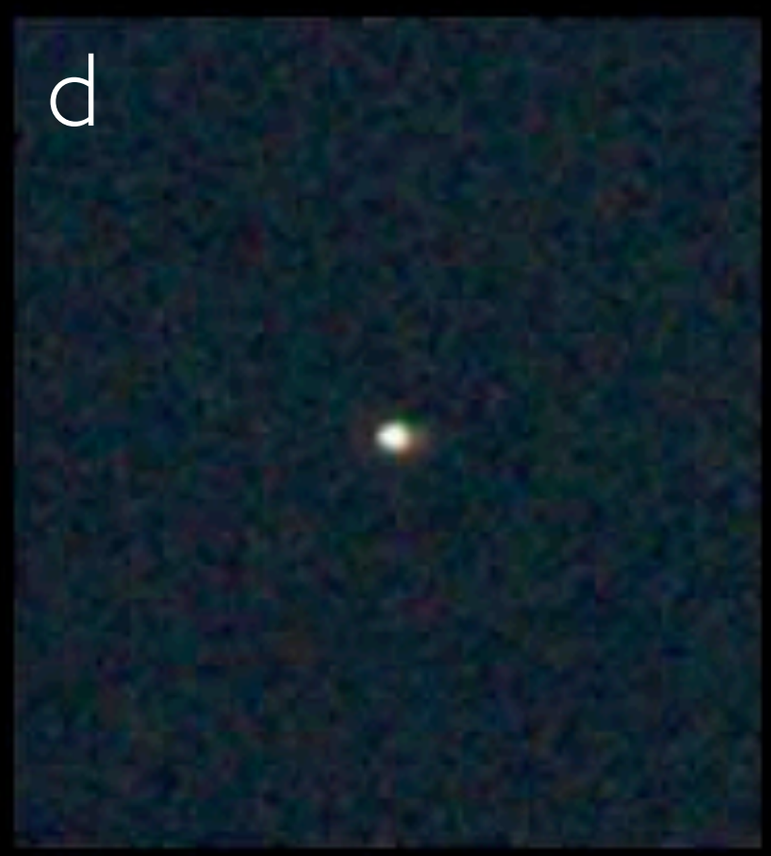
Spectropolarimetry of Planet Earth

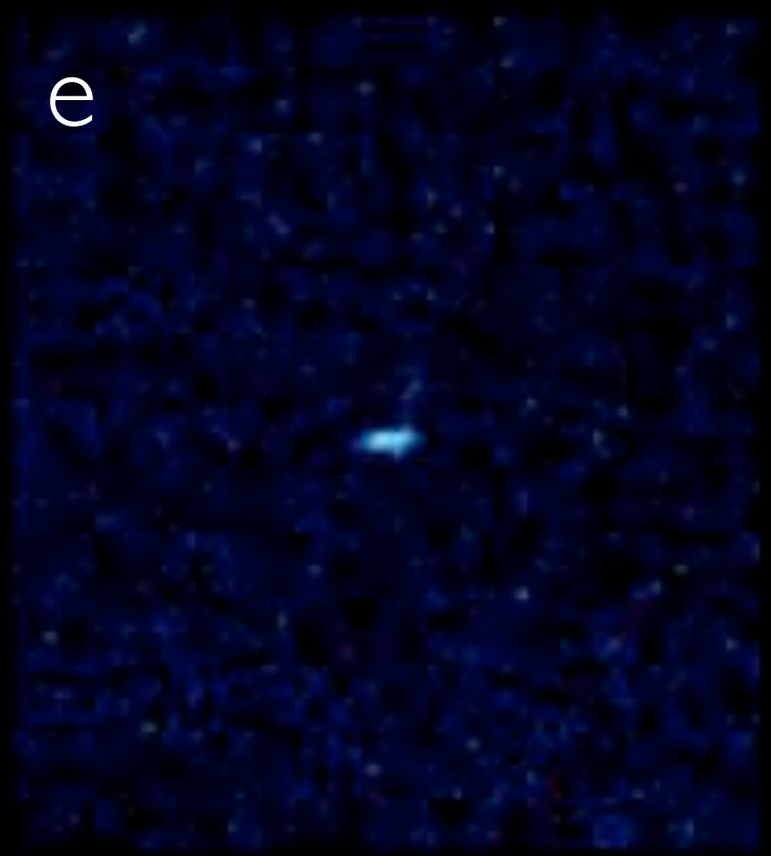
M. Sterzik (European Southern Observatory)
S. Bagnulo (Armagh Observagory)
E. Palle (Insituto de Astrofisica de Canarias)

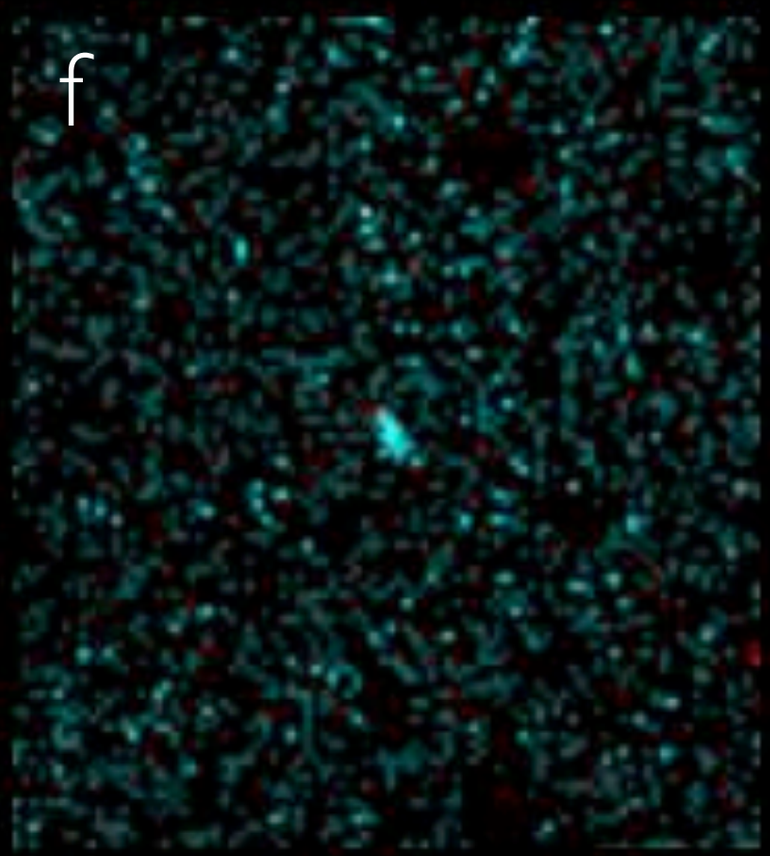




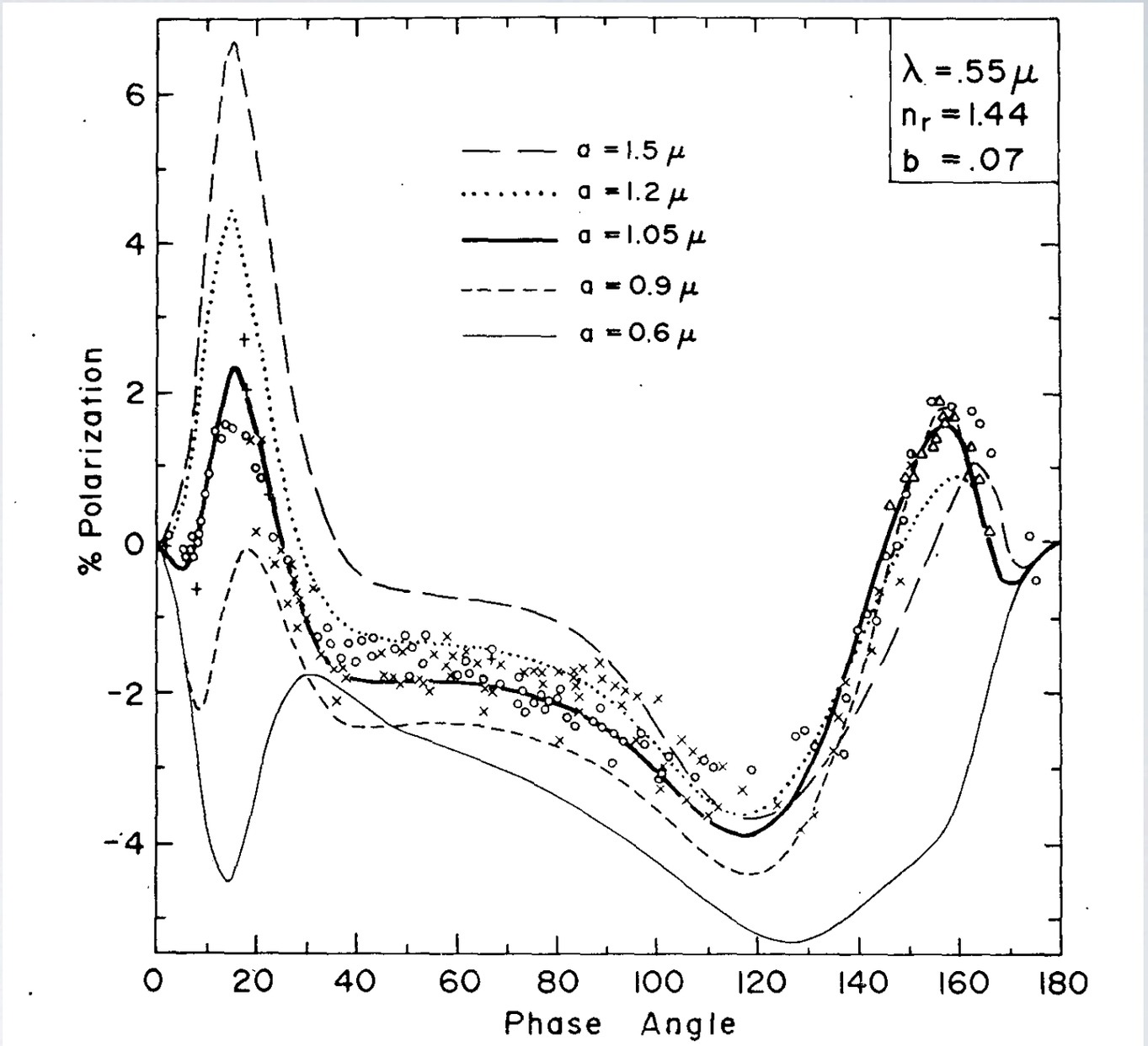
Which World Holds Life?







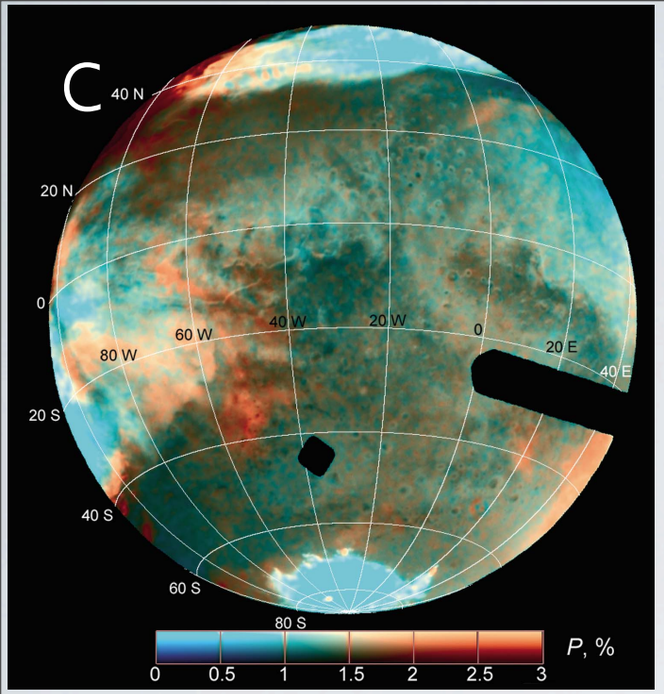
Thick atmosphere dominated by (multiple) Mie scattering



Only polarisation measurements in the 1970' reveal:

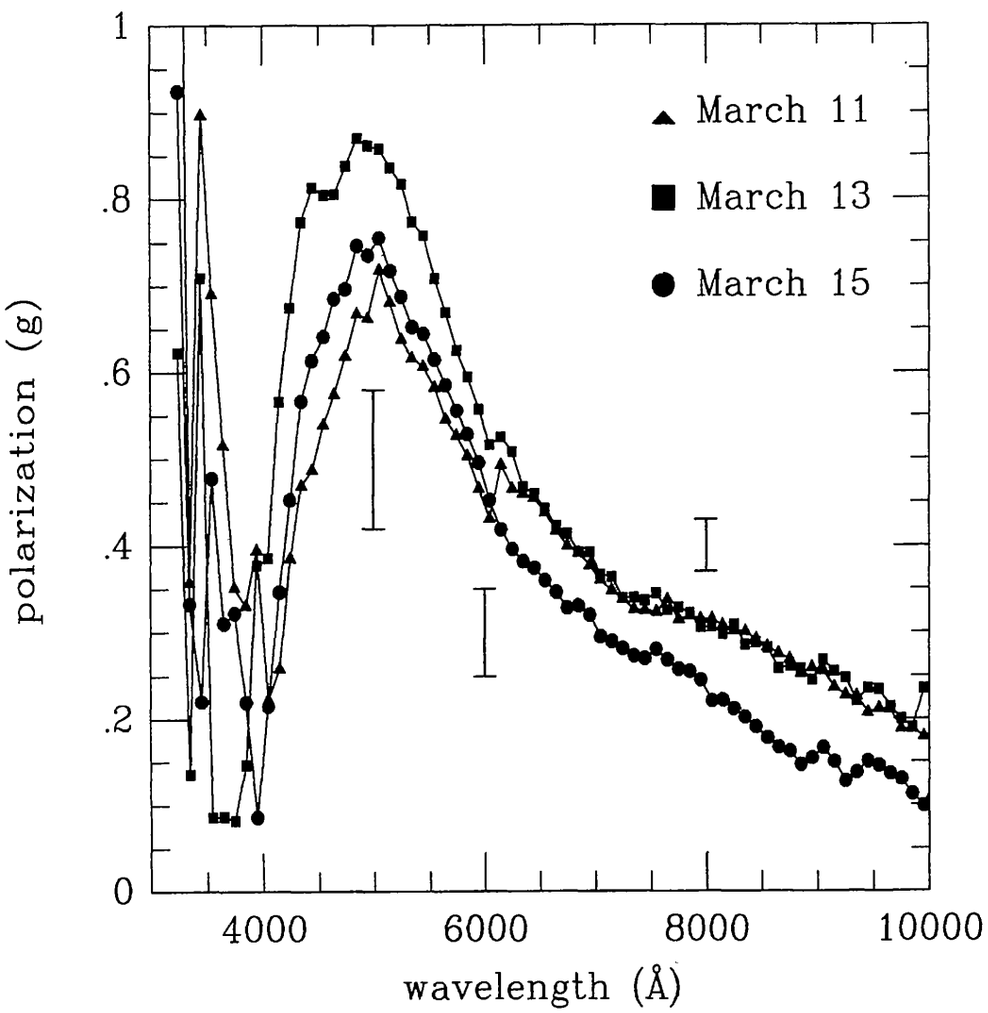
refraction index (H_2SO_4)
particle shape (spherical)
size distribution (1 μm)
cloud top pressure height

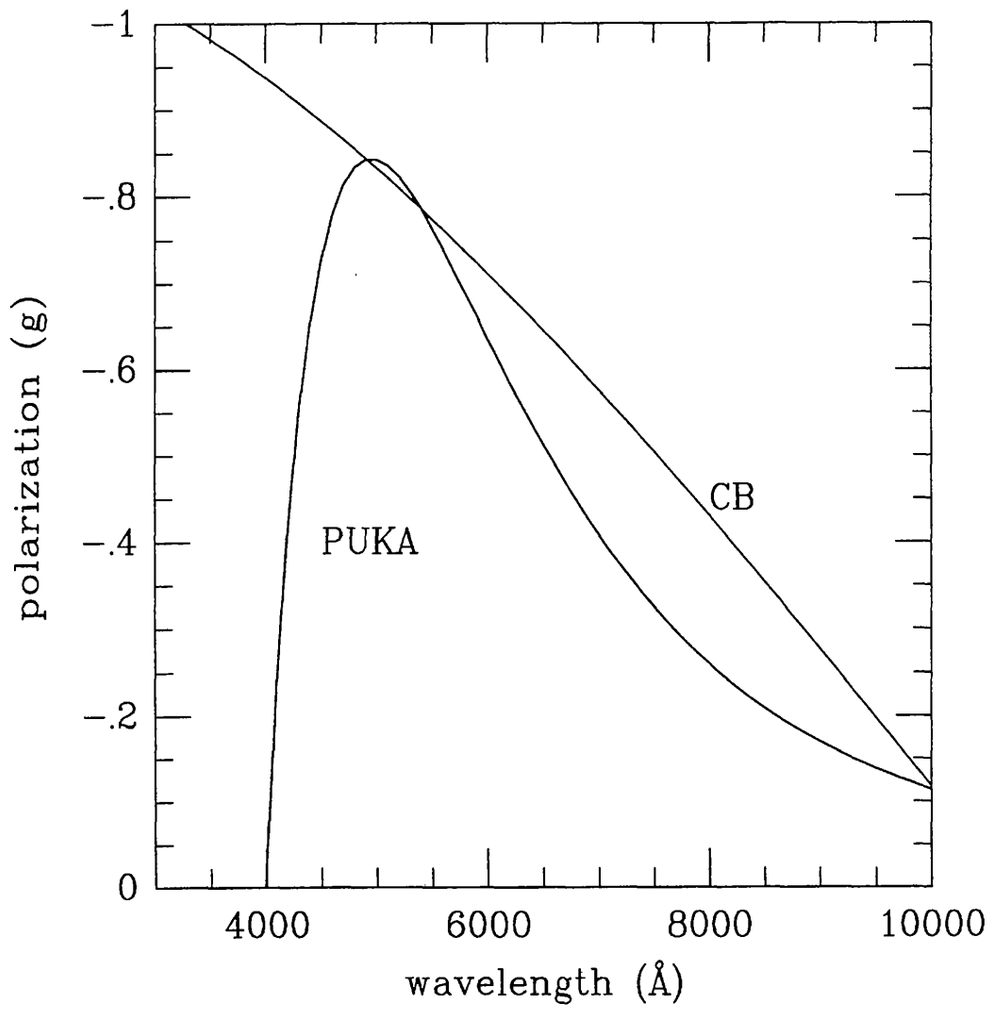
Hansen, J. E. & Hovenier, J. W. Interpretation of the polarization of Venus. *Journal of Atmospheric Science* **31**, 1137–1160 (1974).



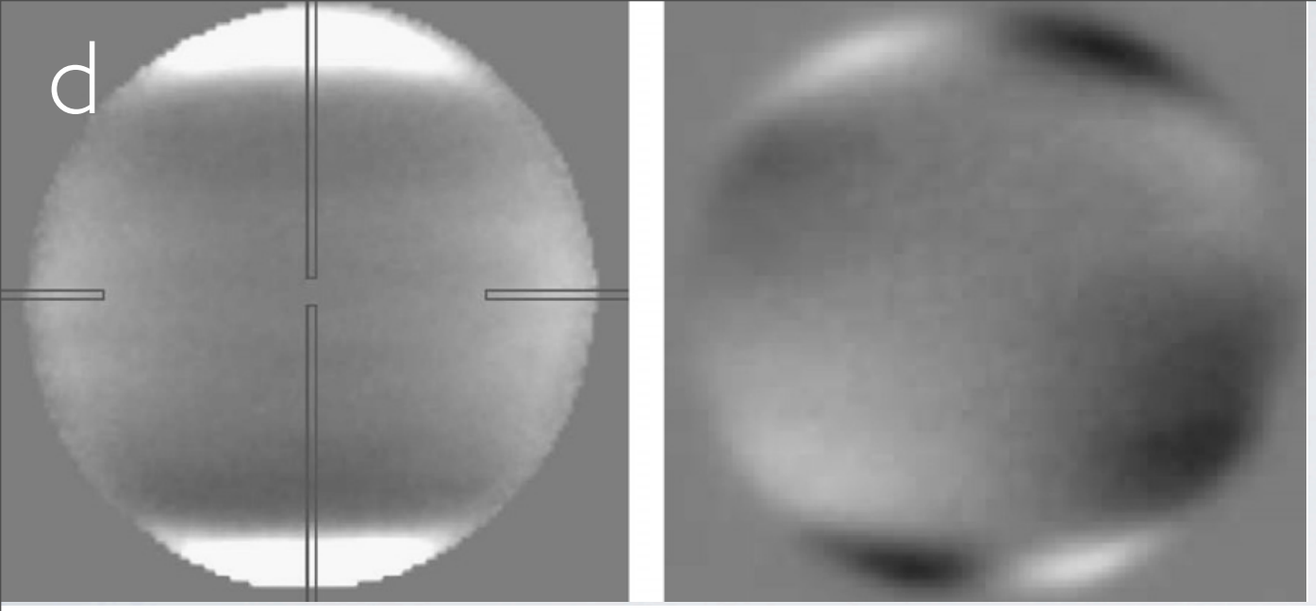
HST 3-band imaging polarimetry: surface regoliths and thin, transient "clouds"

Shkuratov, Y. *et al.* Hubble Space Telescope imaging polarimetry of Mars during the 2003 opposition. *Icarus* **176**, 1–11 (2005).



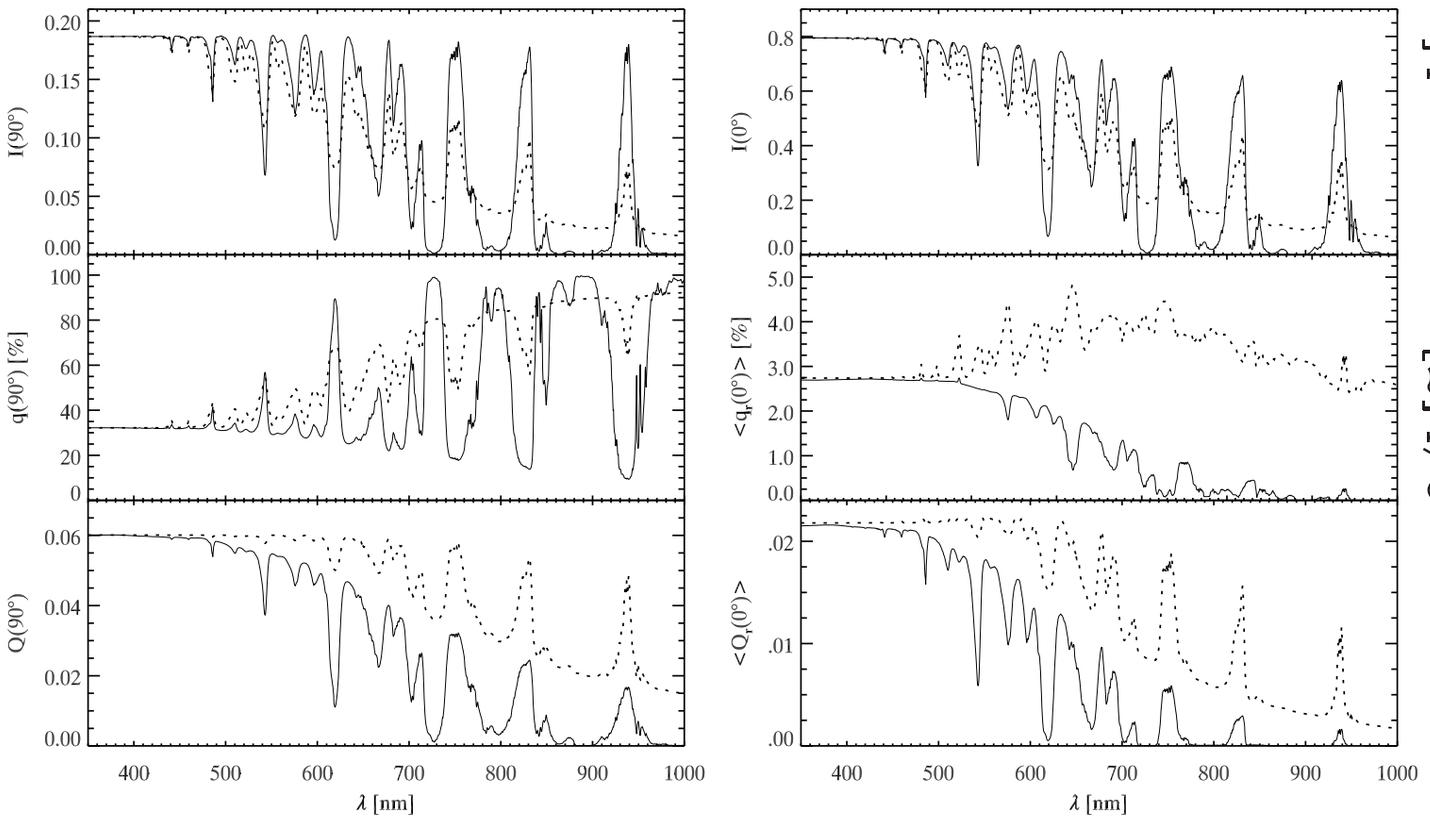


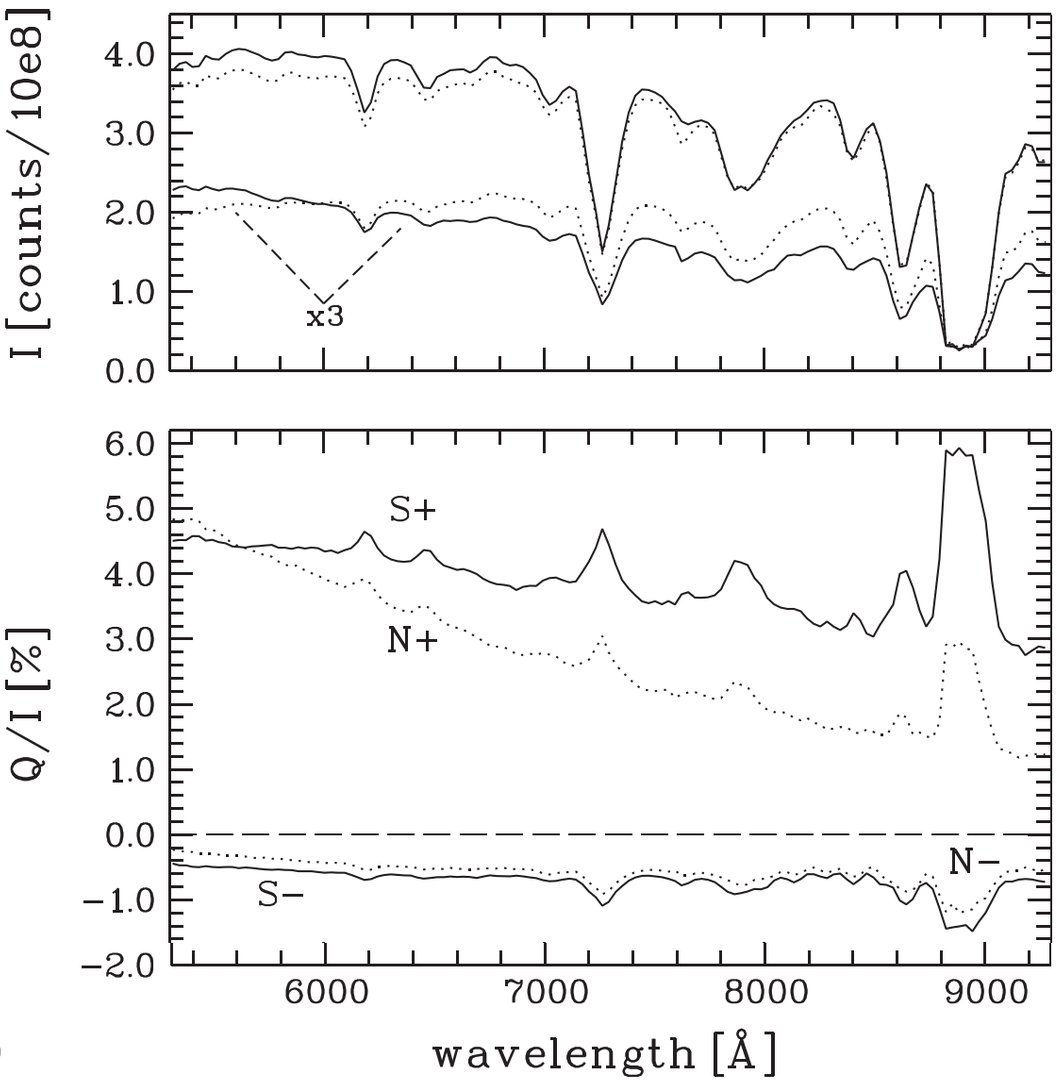
Fox, G. K. Spectropolarimetry of Mars: the development of two polarization reversals. *Monthly Notices of the Royal Astronomical Society* **286**, 963–968 (1997).



ZIMPOL and EFOSC2 backscatter geometry "limb" polarization

MC: Rayleigh-atmosphere with Methane absorption





Buenzli, E. & Schmid, H. M. A grid of polarization models for Rayleigh scattering planetary atmospheres. *A&A* **504**, 259–276 (2009).

Schmid, H. M., Joos, F., Buenzli, E. & Gisler, D. Long slit spectropolarimetry of Jupiter and Saturn. *Icarus* **212**, 701–713 (2011).

e and f are similar.

b

Friday, March 23, 2012

Early Polarimetry of Planet Earth

Difficult!

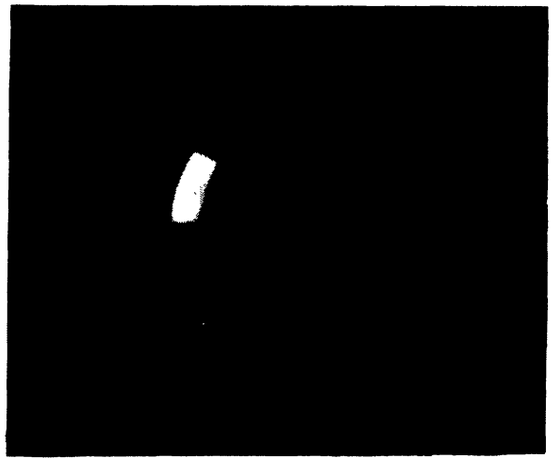
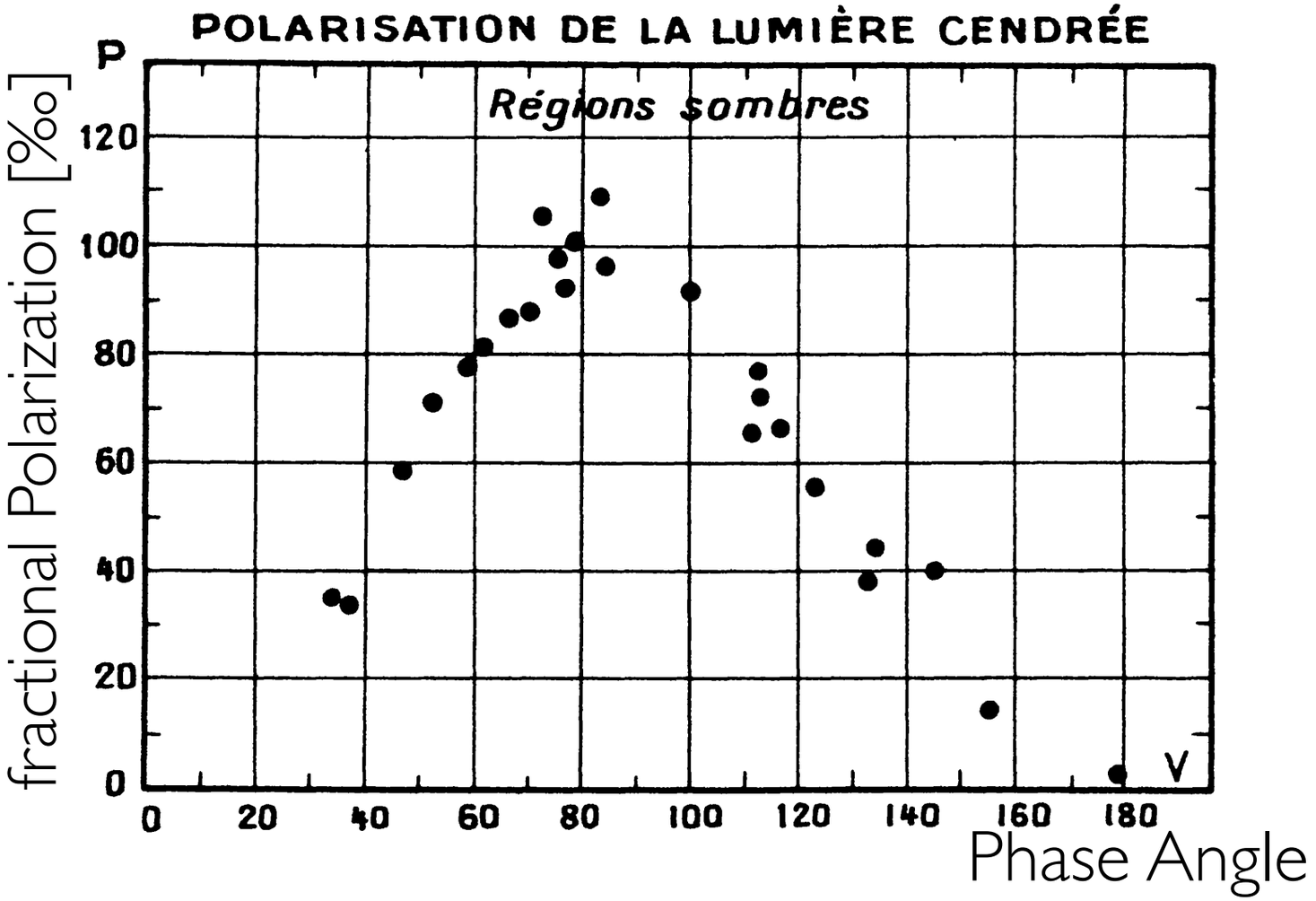


FIG. 22. — Photographie de la lumière cendrée débordant le cache du coronographe (à droite). Contre le bord du cache, les dernières montagnes le long du terminateur lunaire.



Wavelength dependency

Le 6 octobre 1950, pour V = 70°, un cliché à travers un filtre rouge de longueur d'onde moyenne 0 μ 63 a donné la proportion de lumière polarisée 35 millièmes, elle était 54 millièmes en lumière vert-jaune vers 0 μ 55.

La polarisation de la lumière cendrée, très sélective, diminue beaucoup dans le rouge.

Moon surface depolarization

Ce calcul très sommaire a seulement la valeur d'une estimation. ***La courbe de polarisation de la Terre se déduit donc de la figure 25, les angles de vision étant supplémentaires et les proportions de lumière polarisées multipliées par***

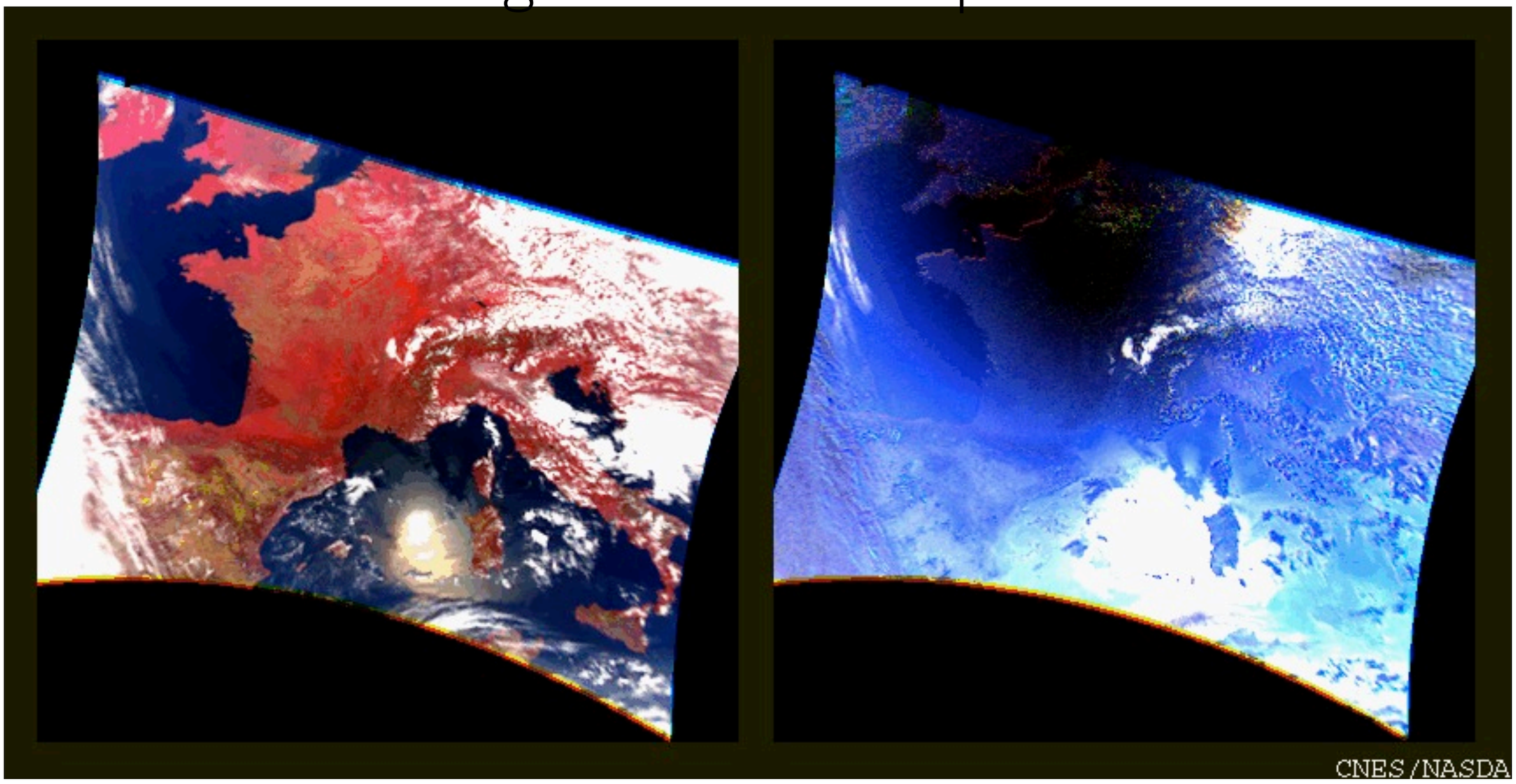
$$\frac{1}{0,33} = 3,3$$

Dollfus, A. Étude des planètes par la polarisation de leur lumière. *Supplements aux Annales d'Astrophysique* **4**, 3–114 (1957).

POLDER Polarimetry of Planet Earth

3-band image

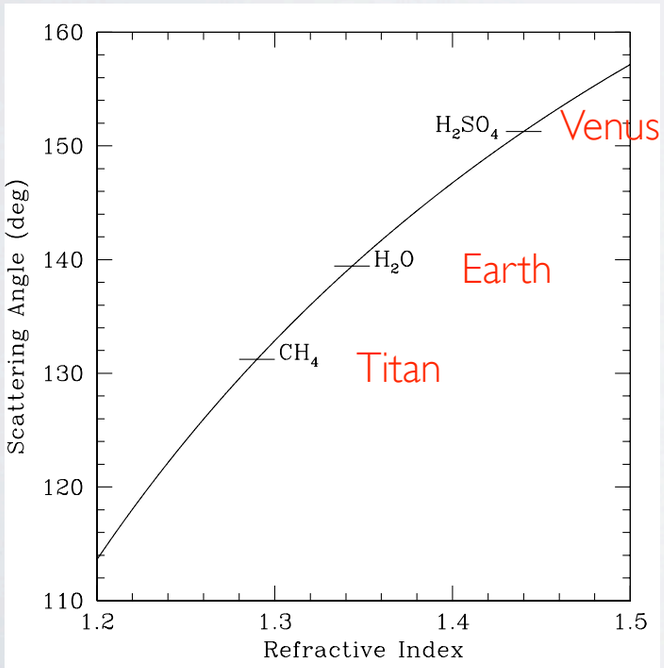
polarization



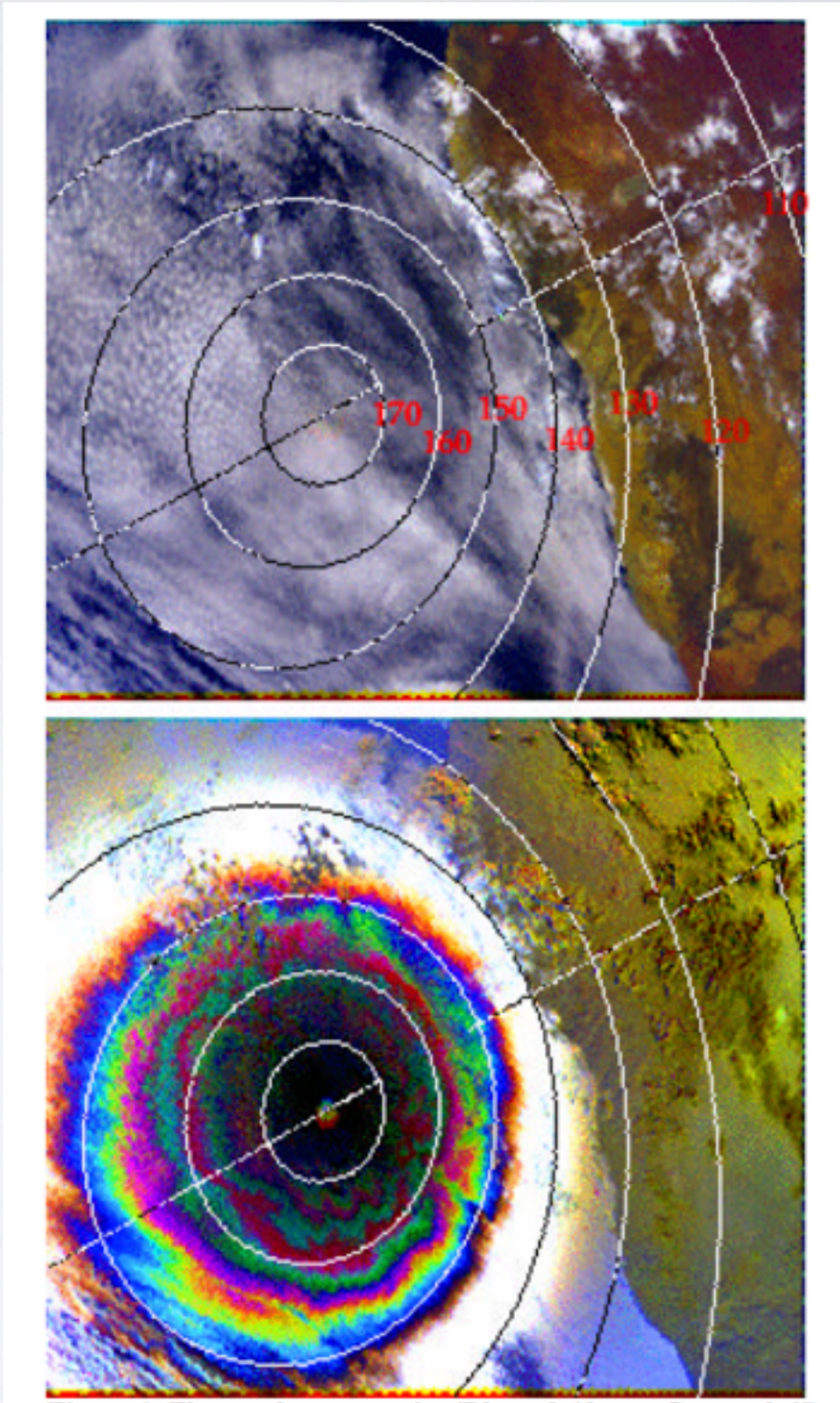
Rayleigh scattering dominated

Polarimetric Signatures of Planet Earth

primary rainbow polarization



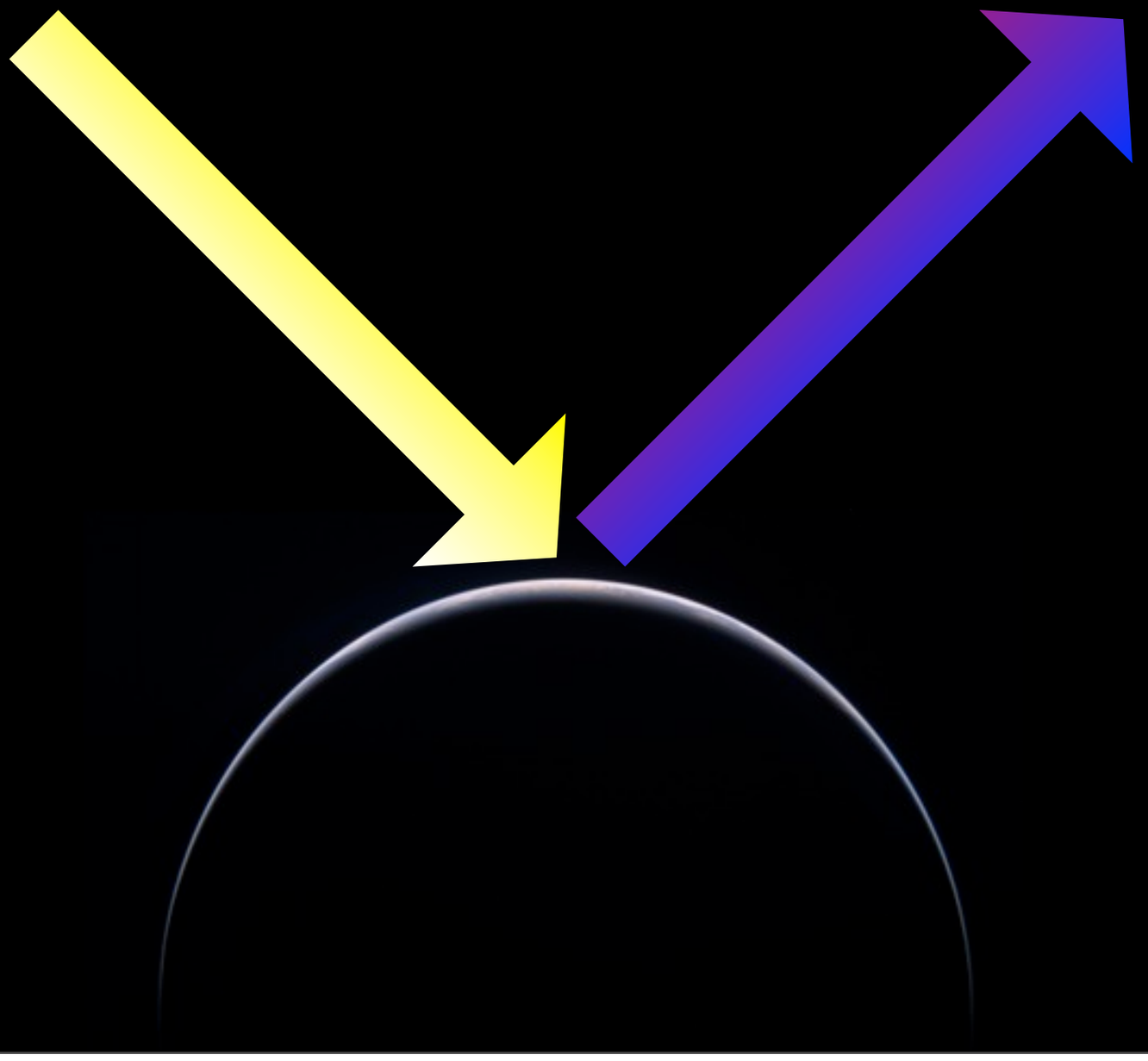
"cloudbow"



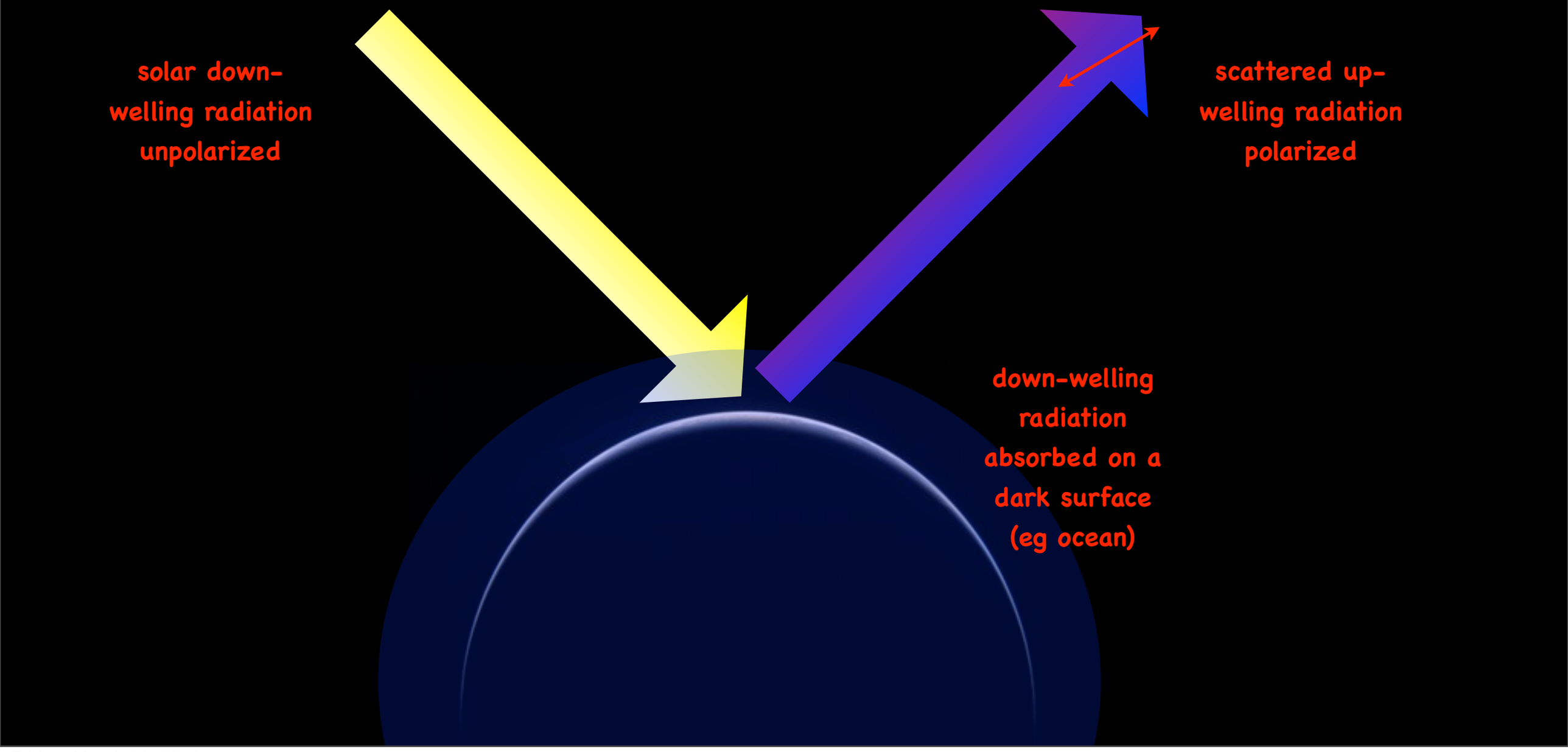
Bailey, J. Rainbows, Polarization, and the Search for Habitable Planets. *Astrobiology* **7**, 320–332 (2007).

Bréon, F. M. & Goloub, P. Cloud droplet effective radius from spaceborne polarization measurements. *Geophysical research letters* **25**, 1879–1882 (1998).

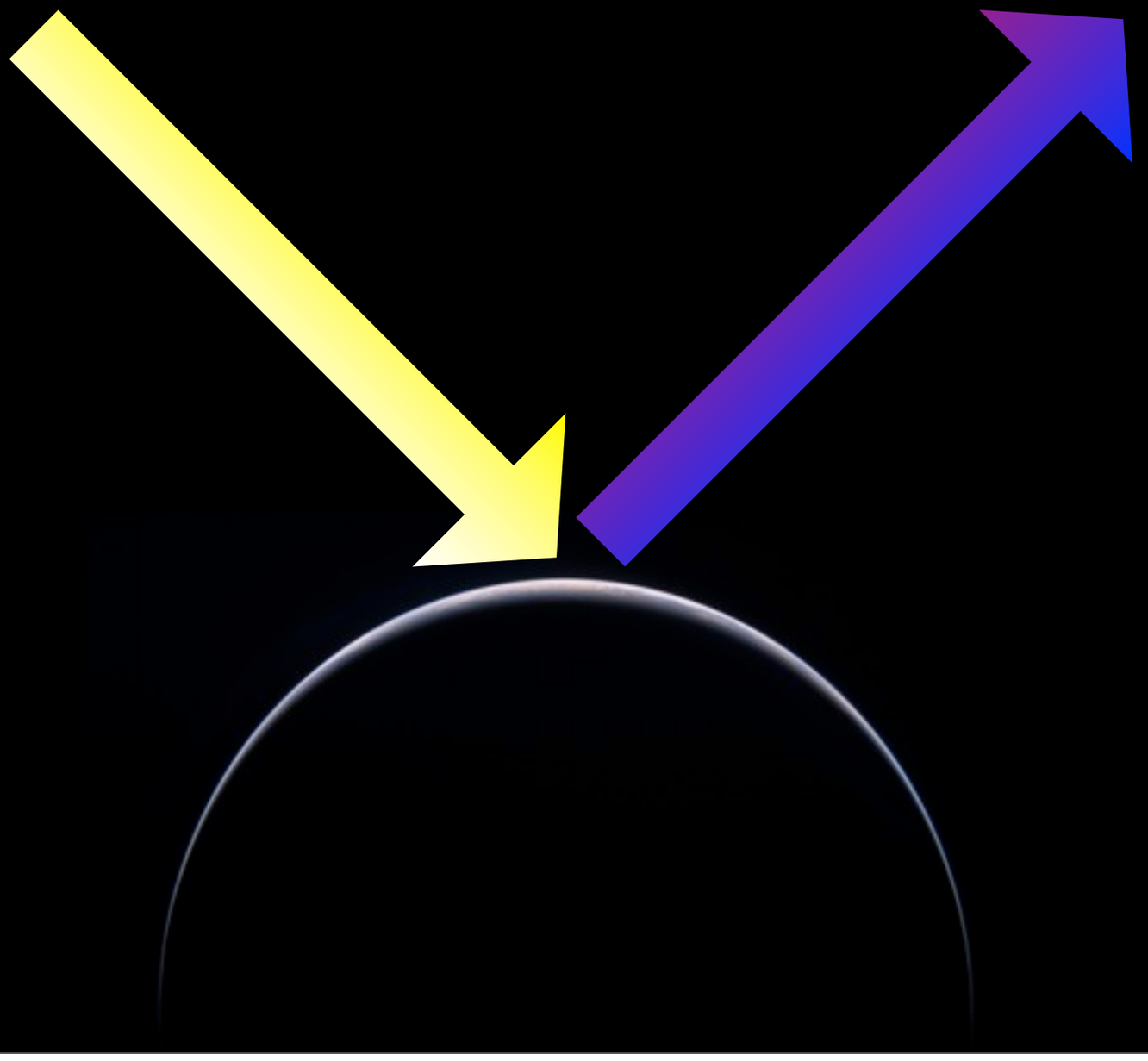
Polarimetric Signatures of Surfaces below a Rayleigh Atmosphere



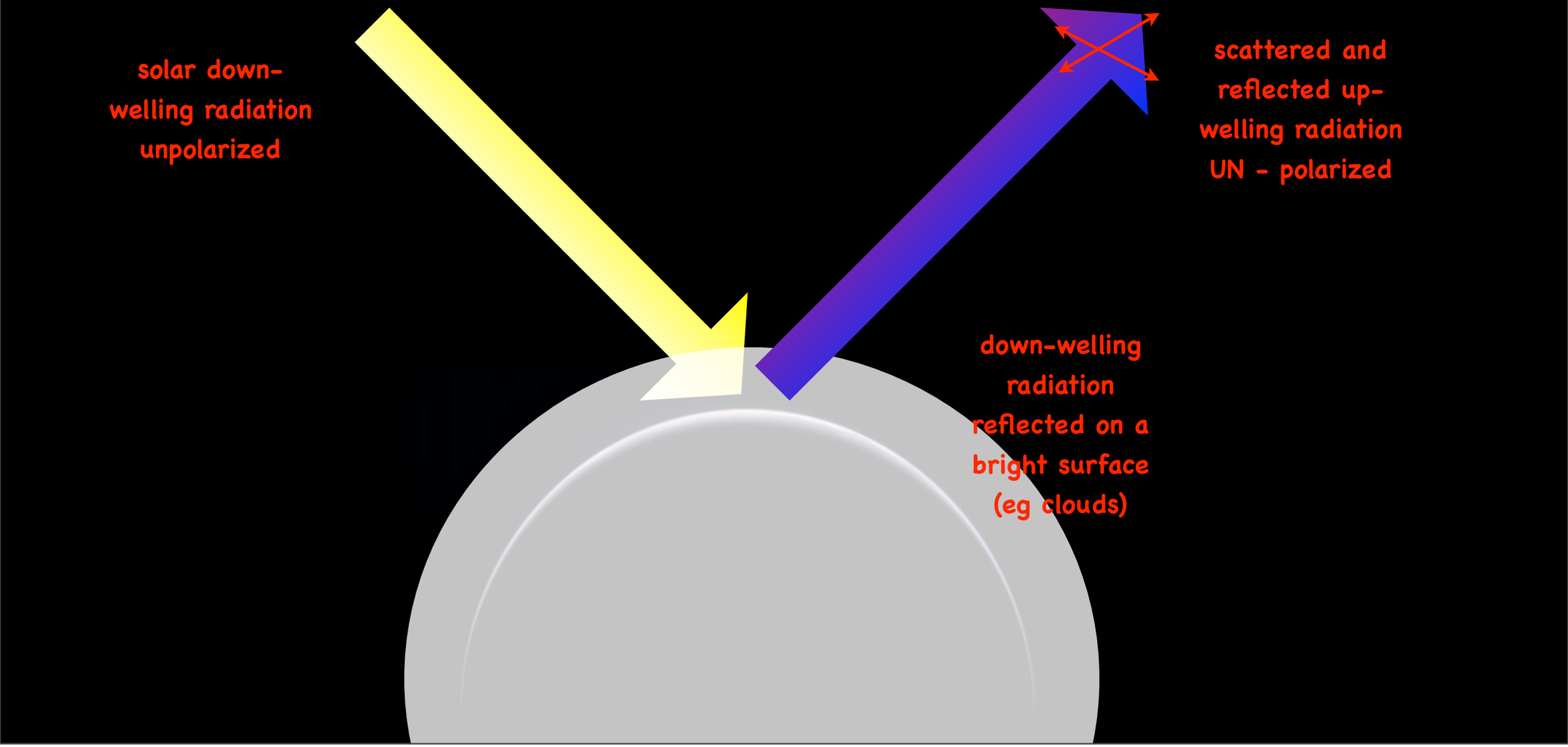
Polarimetric Signatures of Surfaces below a Rayleigh Atmosphere



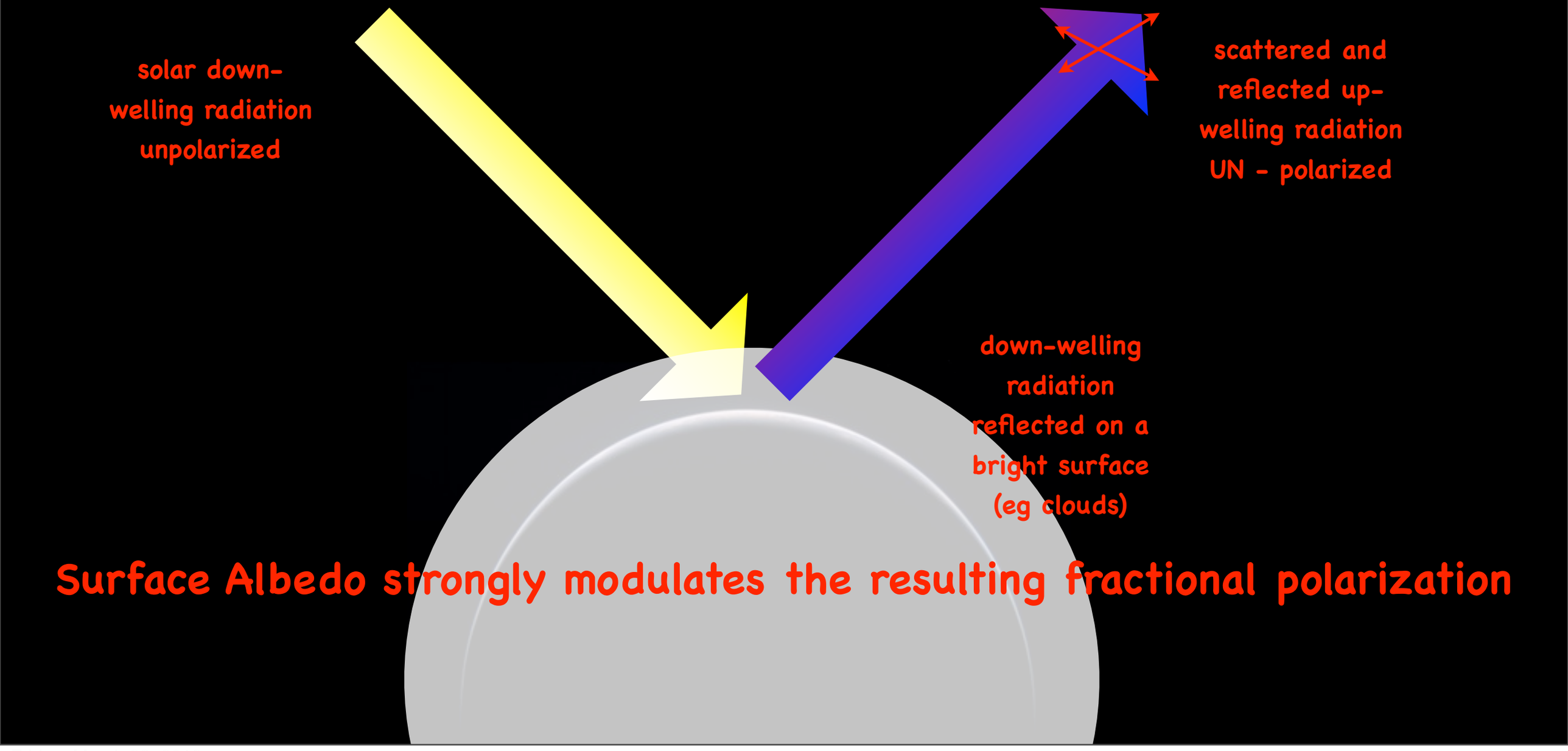
Polarimetric Signatures of Surfaces below a Rayleigh Atmosphere



Polarimetric Signatures of Surfaces below a Rayleigh Atmosphere



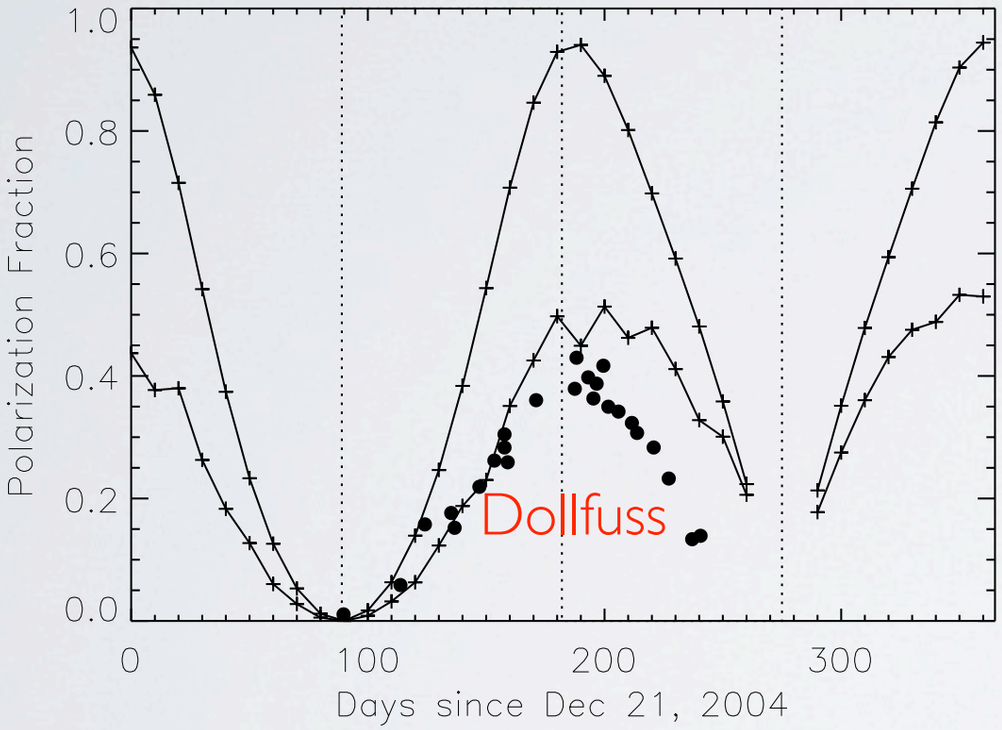
Polarimetric Signatures of Surfaces below a Rayleigh Atmosphere



Surface Albedo strongly modulates the resulting fractional polarization

Polarimetric Signatures of Planet Earth

pure ocean surface

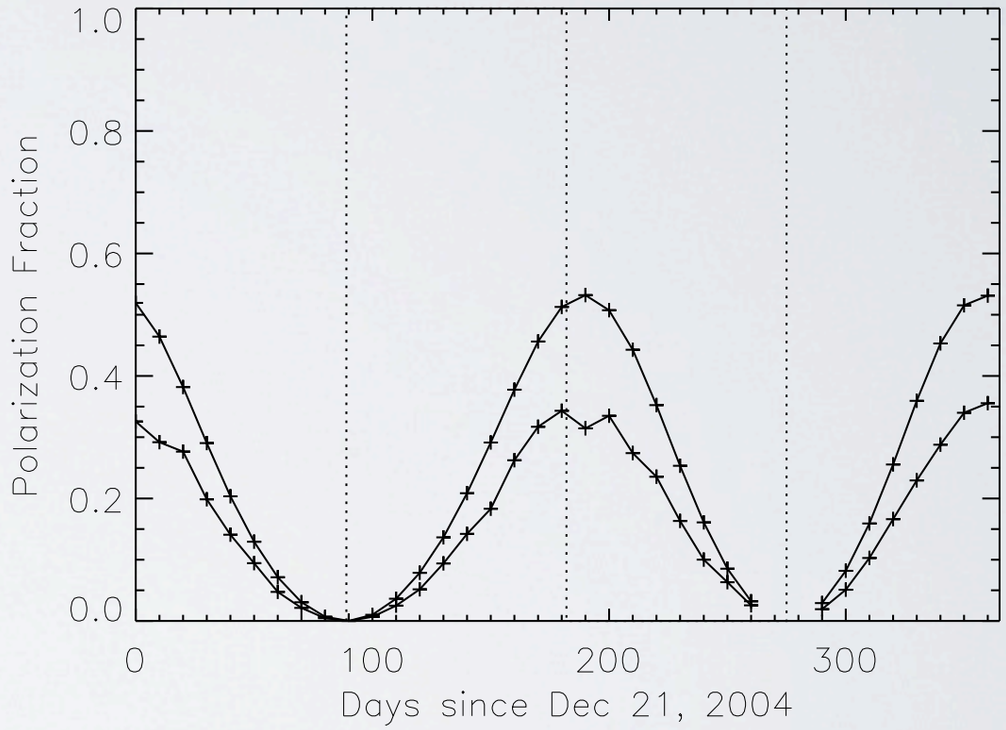


Phase Angle

no clouds

clouds

pure land surface

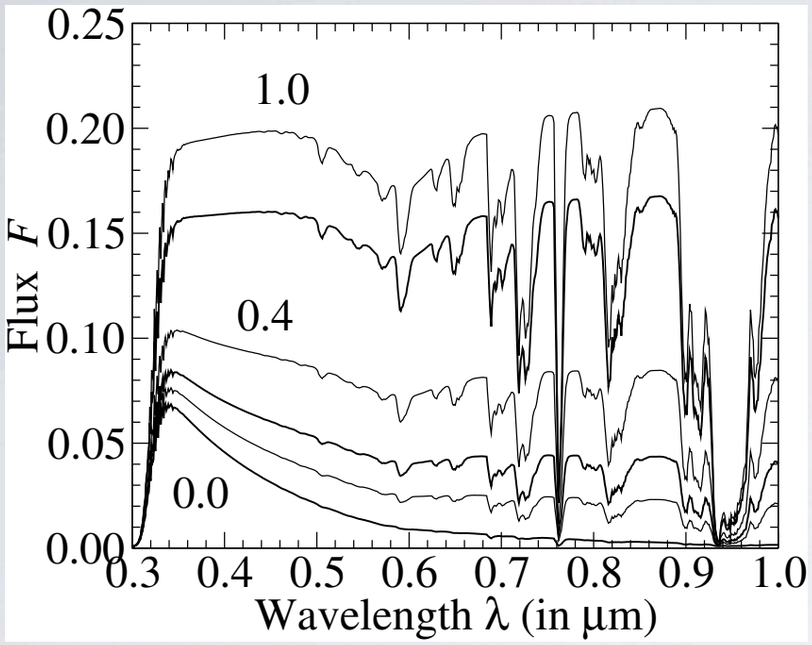


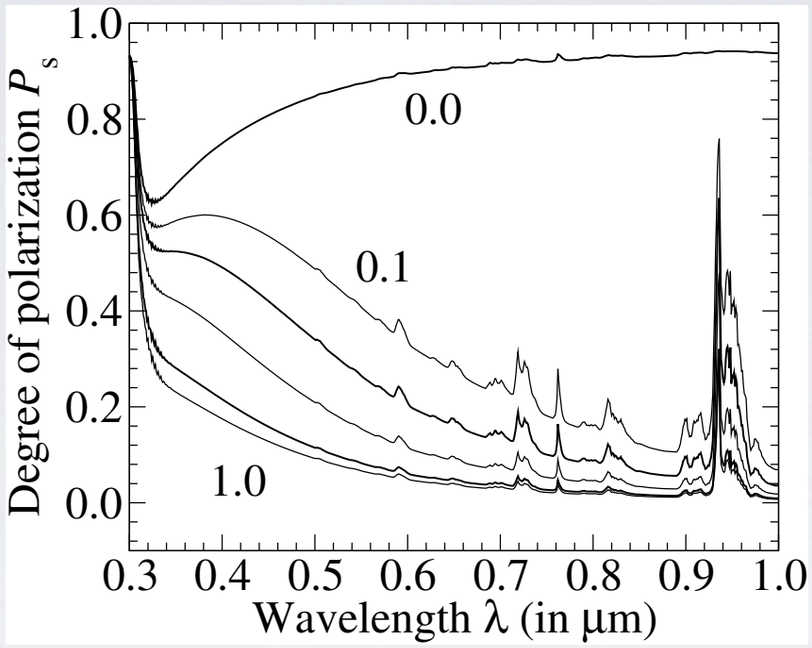
Phase Angle

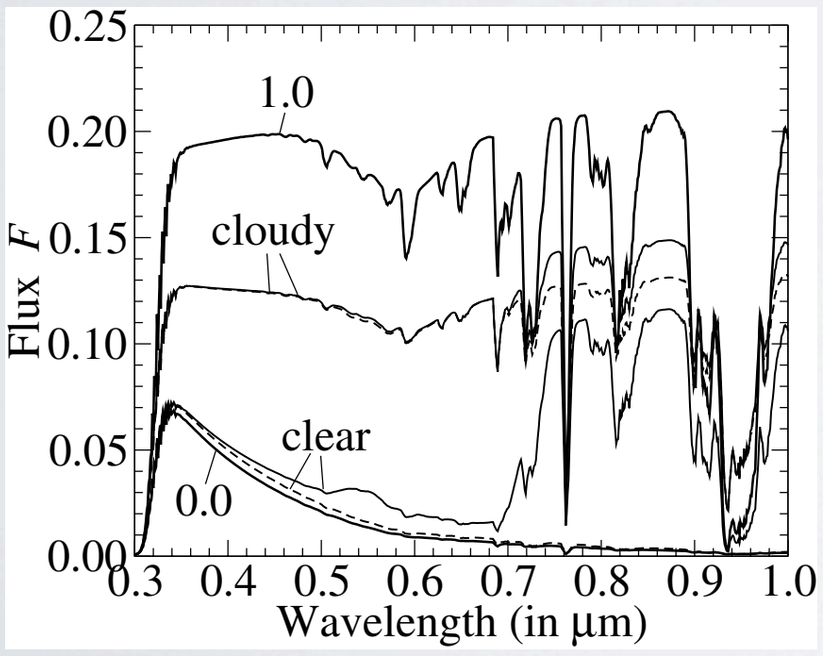
McCullough, P. R. Models of Polarized Light from Oceans and Atmospheres of Earth-like Extrasolar Planets. *arXiv* **astro-ph**, (2006).

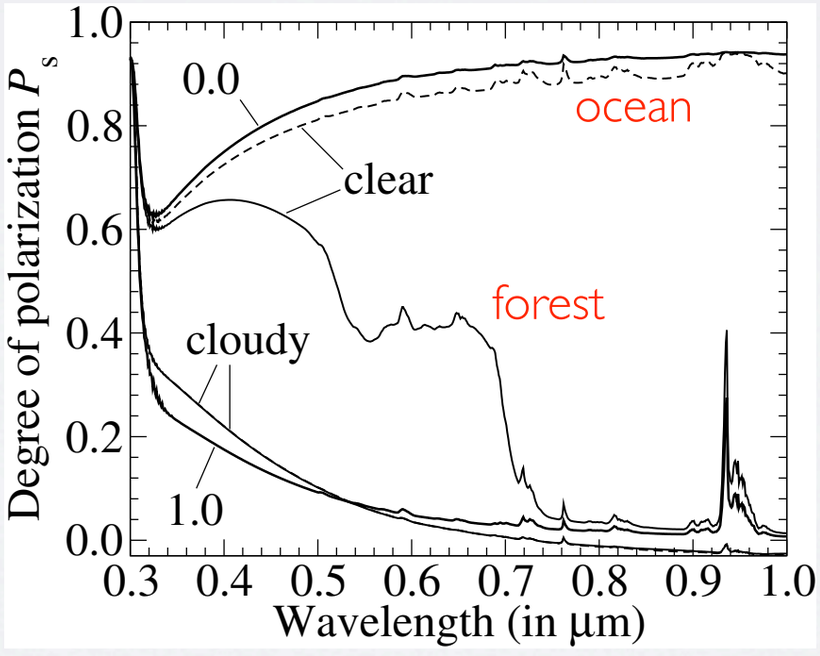
Williams, D. M. & Gaidos, E. Detecting the glint of starlight on the oceans of distant planets. *Icarus* **195**, 927–937 (2008).

Models of the Earth's Polarization









VRT calc. include

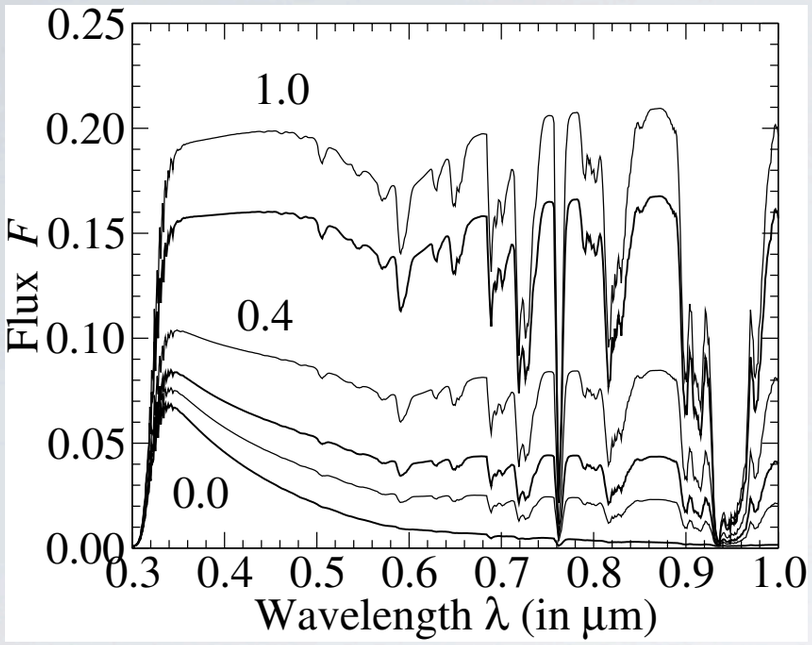
Rayleigh
phase angle
ocean
clouds
"vegetation"

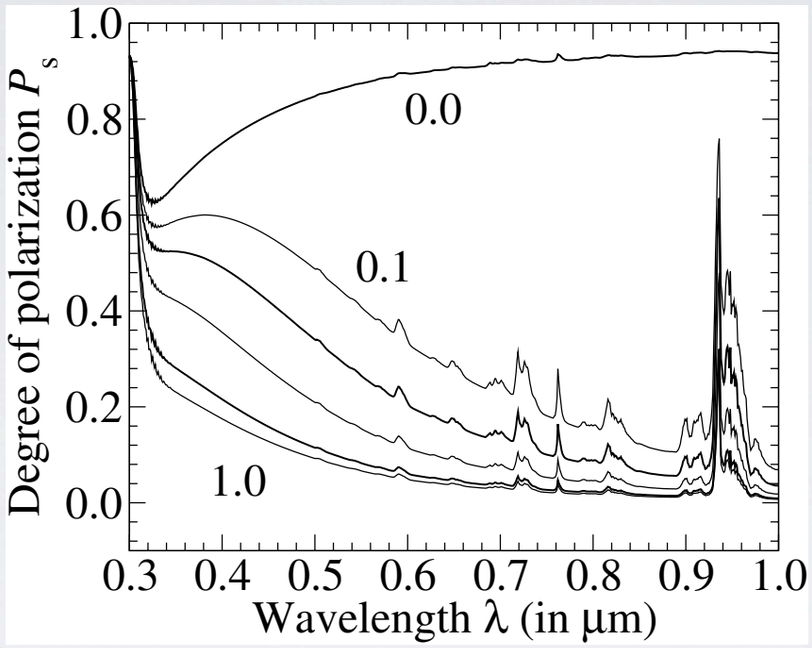
do NOT include

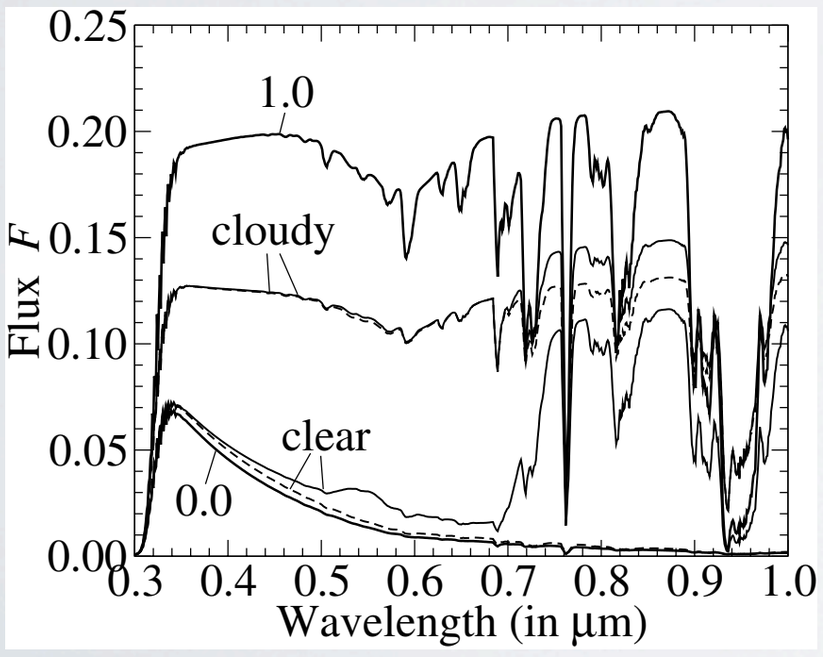
inhomogenities
realistic clouds
aerosols/haze
realistic surfaces

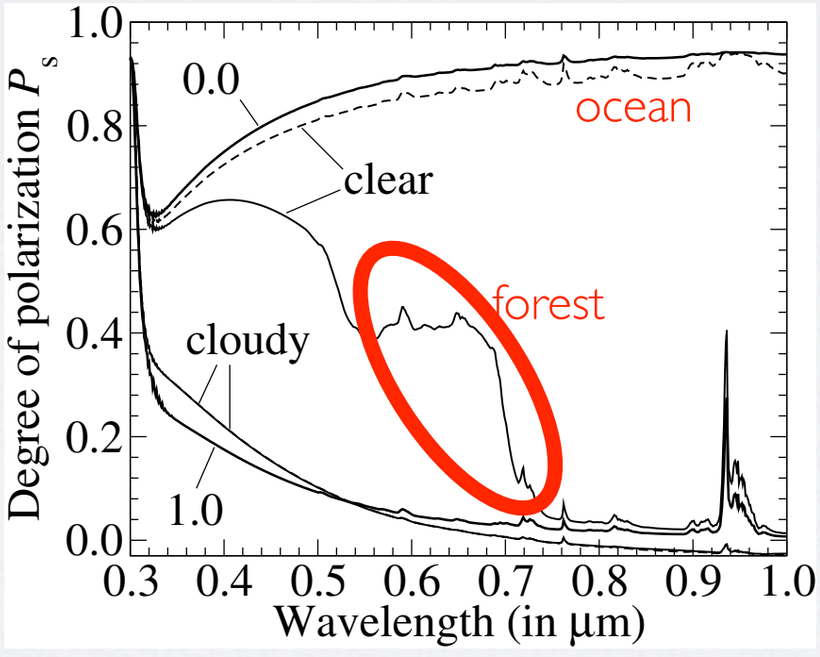
Stam, D. M. Spectropolarimetric signatures of Earth-like extrasolar planets. *A&A* **482**, 989–1007 (2008)

Models of the Earth's Polarization









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realistic surfaces

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

Observations of Earth's Polarization

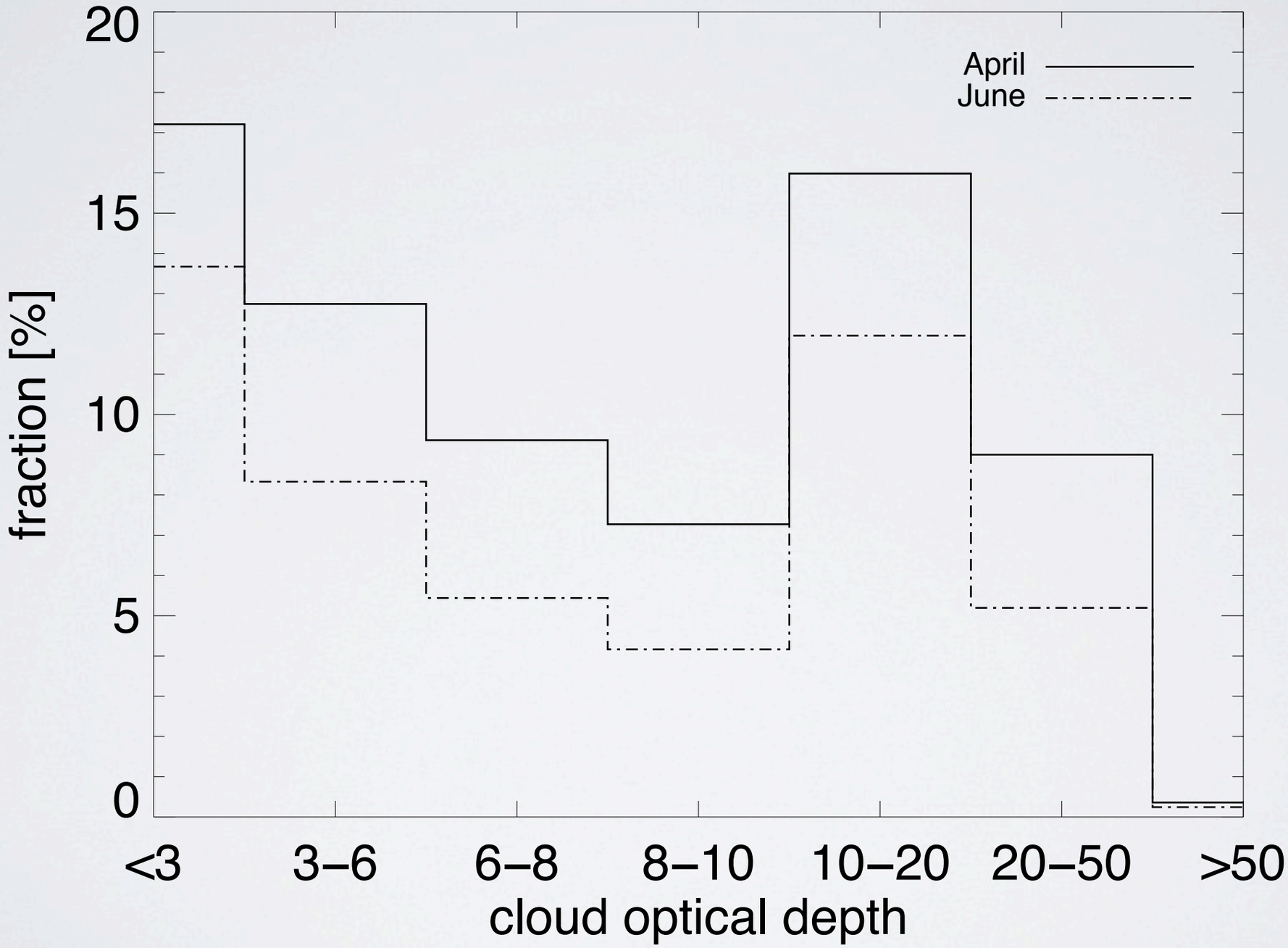
Sterzik, M. F., Bagnulo, S. & Pallé, E. Biosignatures as revealed by spectropolarimetry of Earthshine. *Nature* **483**, 64–66 (2012).

http://www.eso.org/public/news/eso1210/

Observations of Earth's Polarization

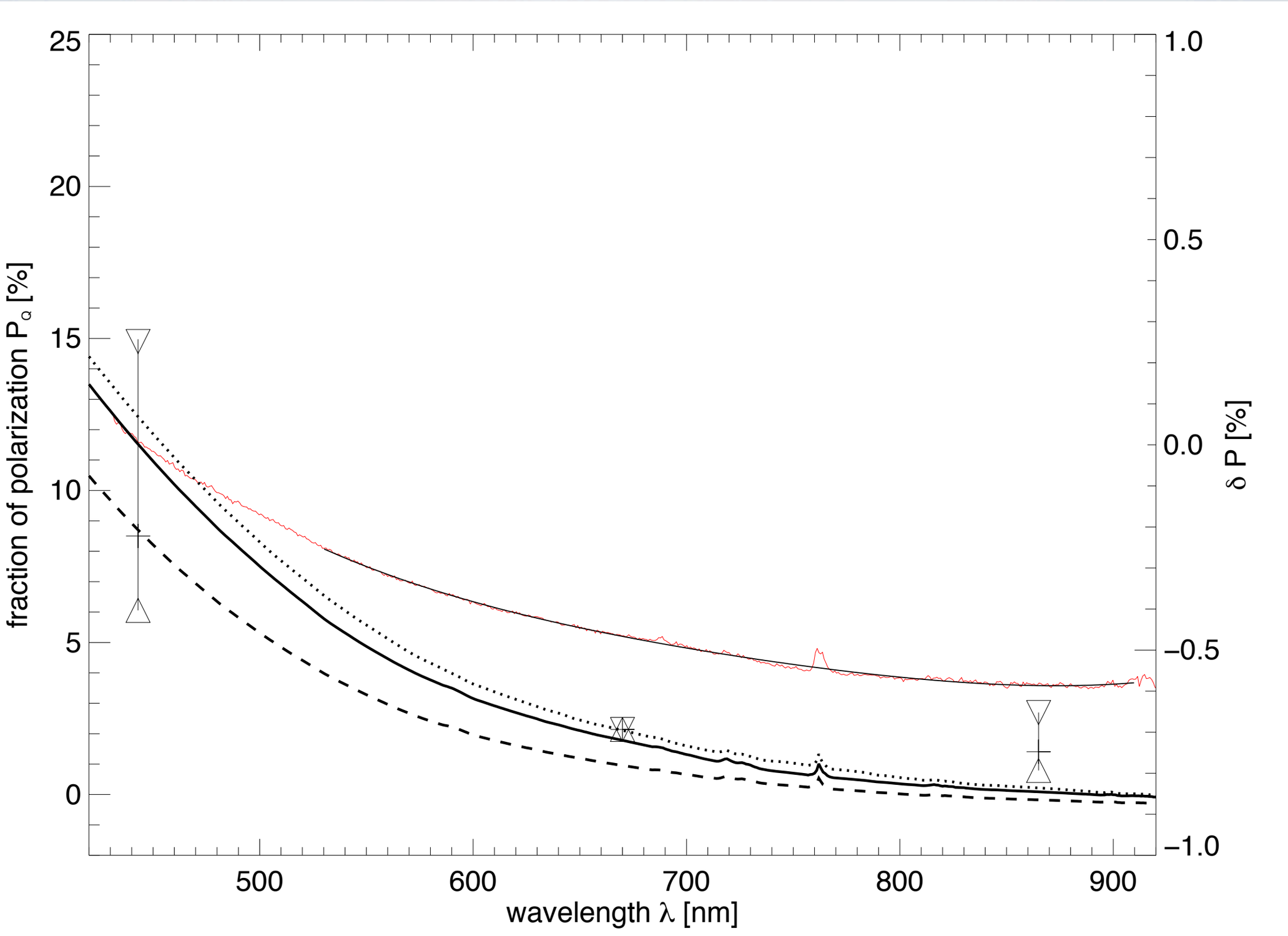
Observing Date	25-Apr-2011:UT09	10-Jun-2011:UT01
View of Earth as seen from the Moon		
Sun-Earth-Moon phase	87 deg	102 deg
ocean fraction in Earthshine	18%	46%
vegetation fraction in Earthshine	7%	3%
tundra, shrub, ice and desert fraction in Earthshine	3%	1%
total cloud fraction in Earthshine	72%	50%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

Cloud Optical Depth Distribution



Cloud data availability through MODIS: disc.sci.gsfc.nasa.gov/giovanni/overview

25-Apr-2011:UT09



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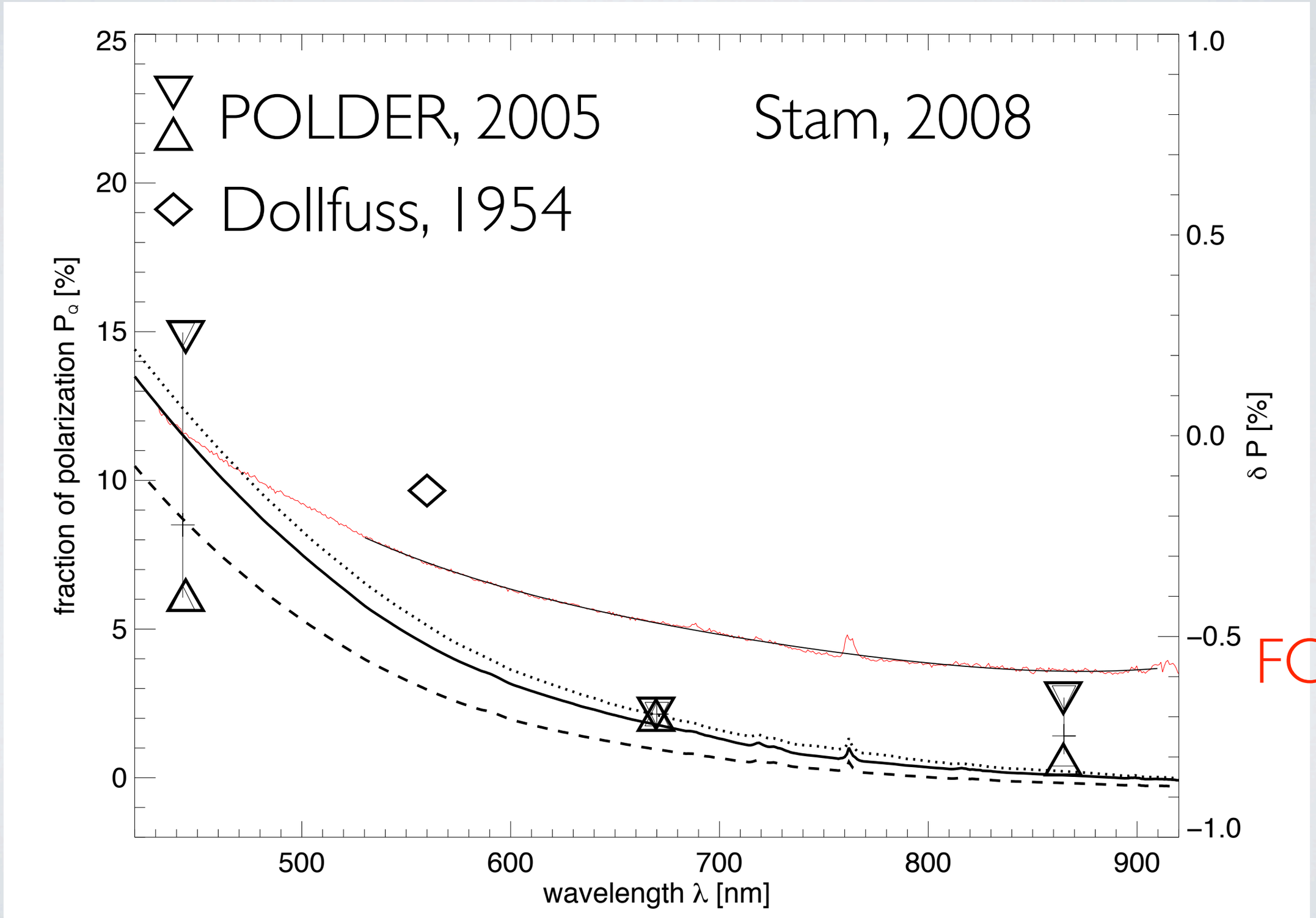

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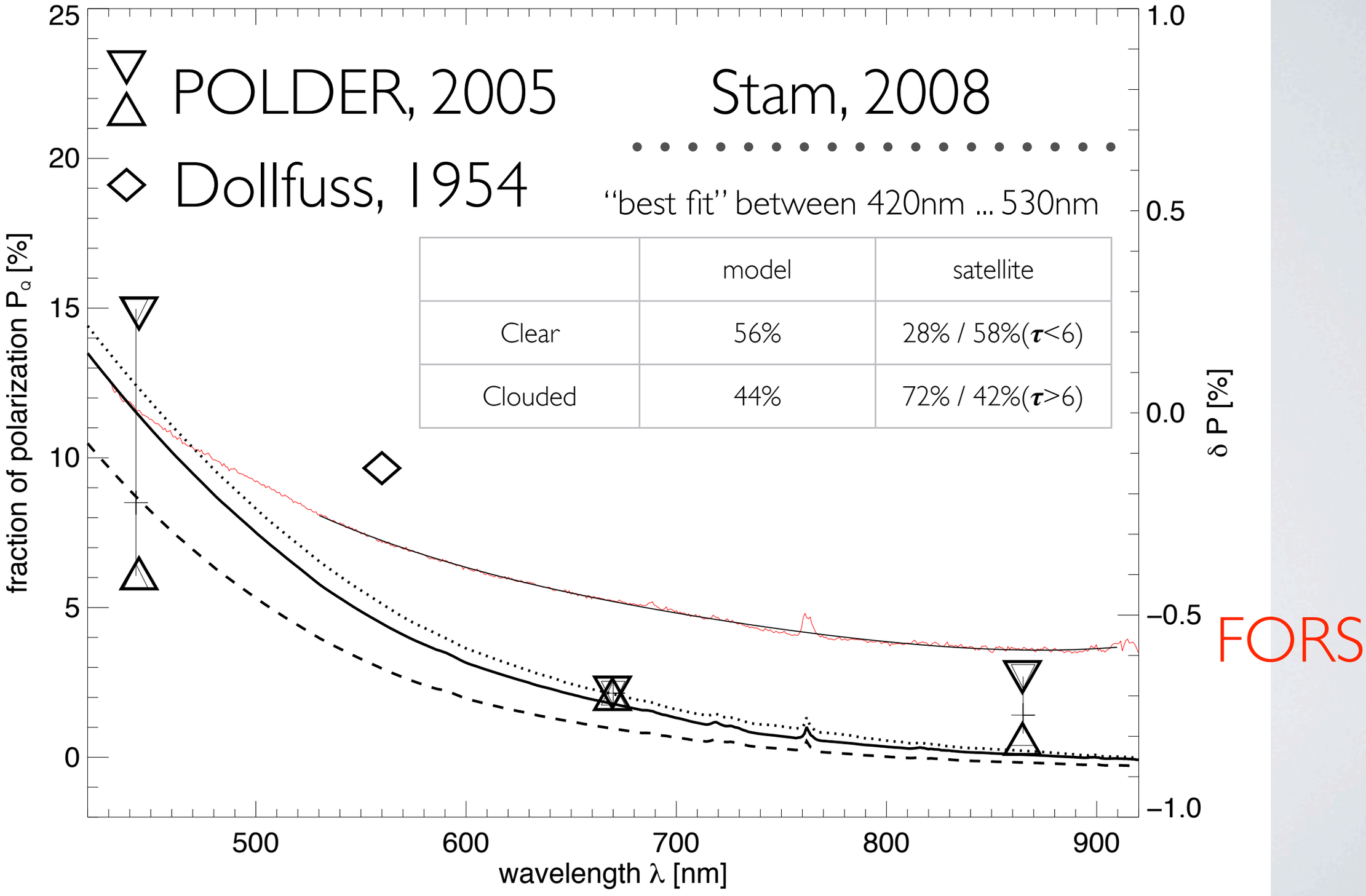
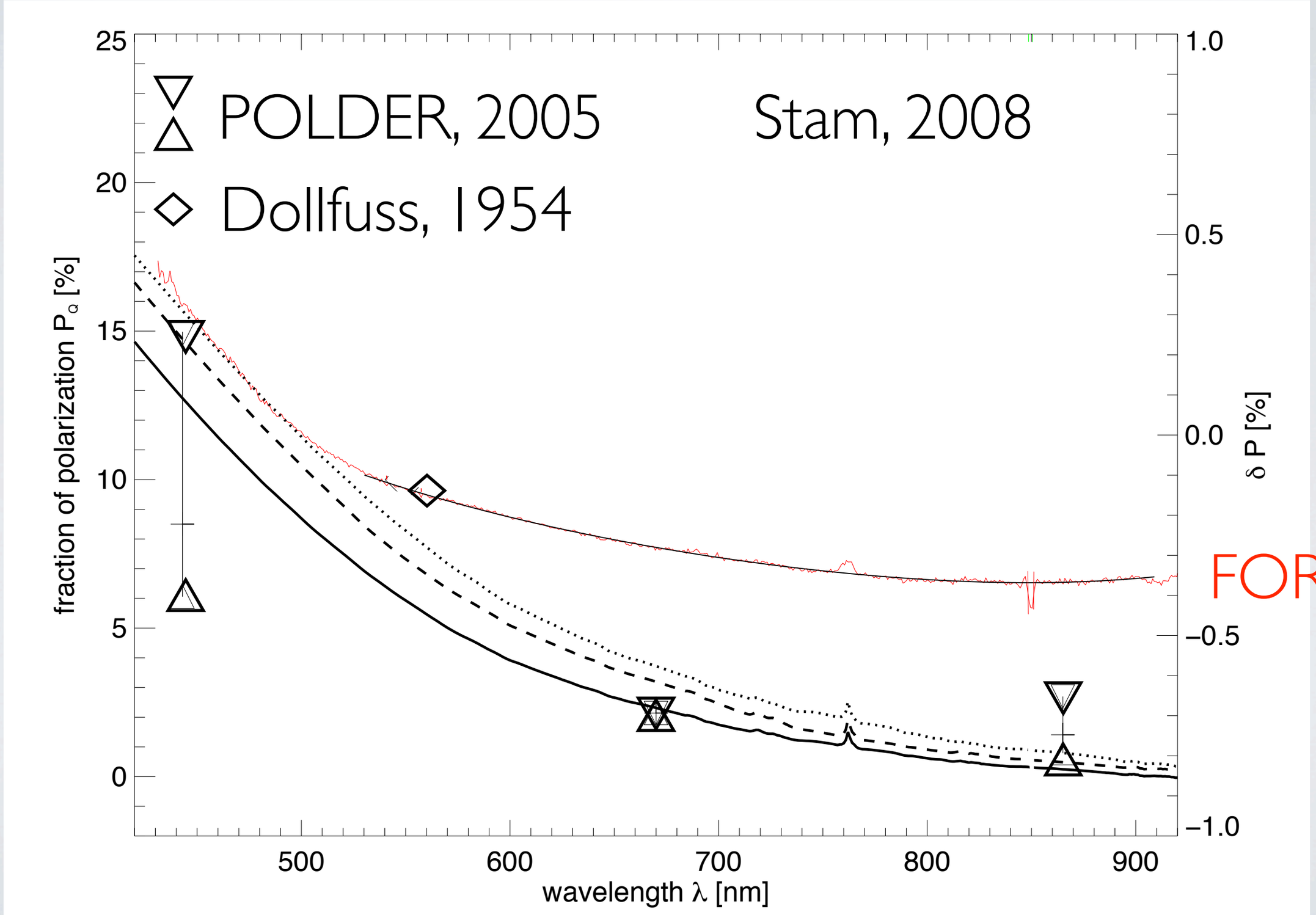


	model	satellite
Clear	56%	28% / 58%(τ<6)
Clouded	44%	72% / 42%(τ>6)

FORS

10-Jun-2011:UT01



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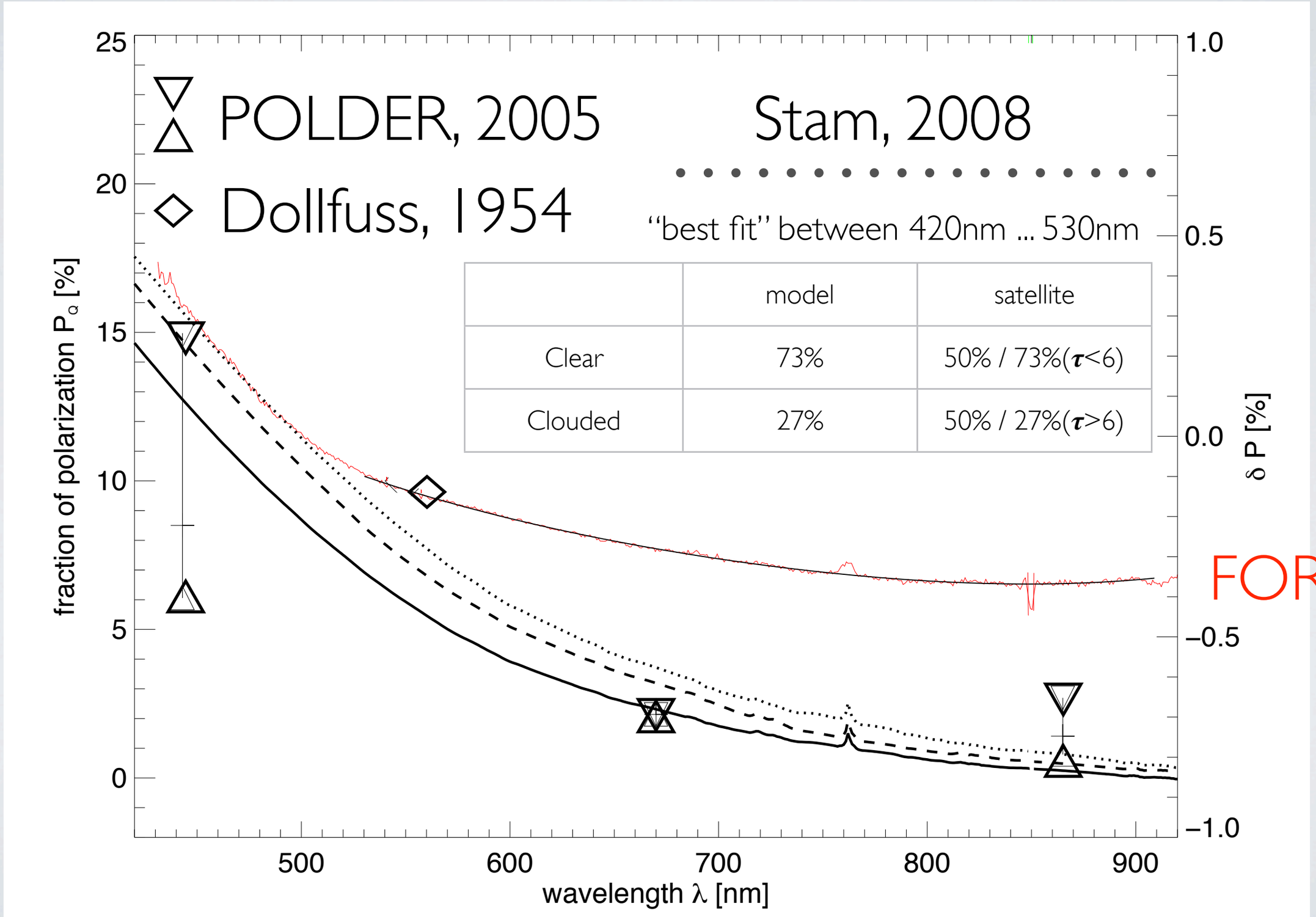
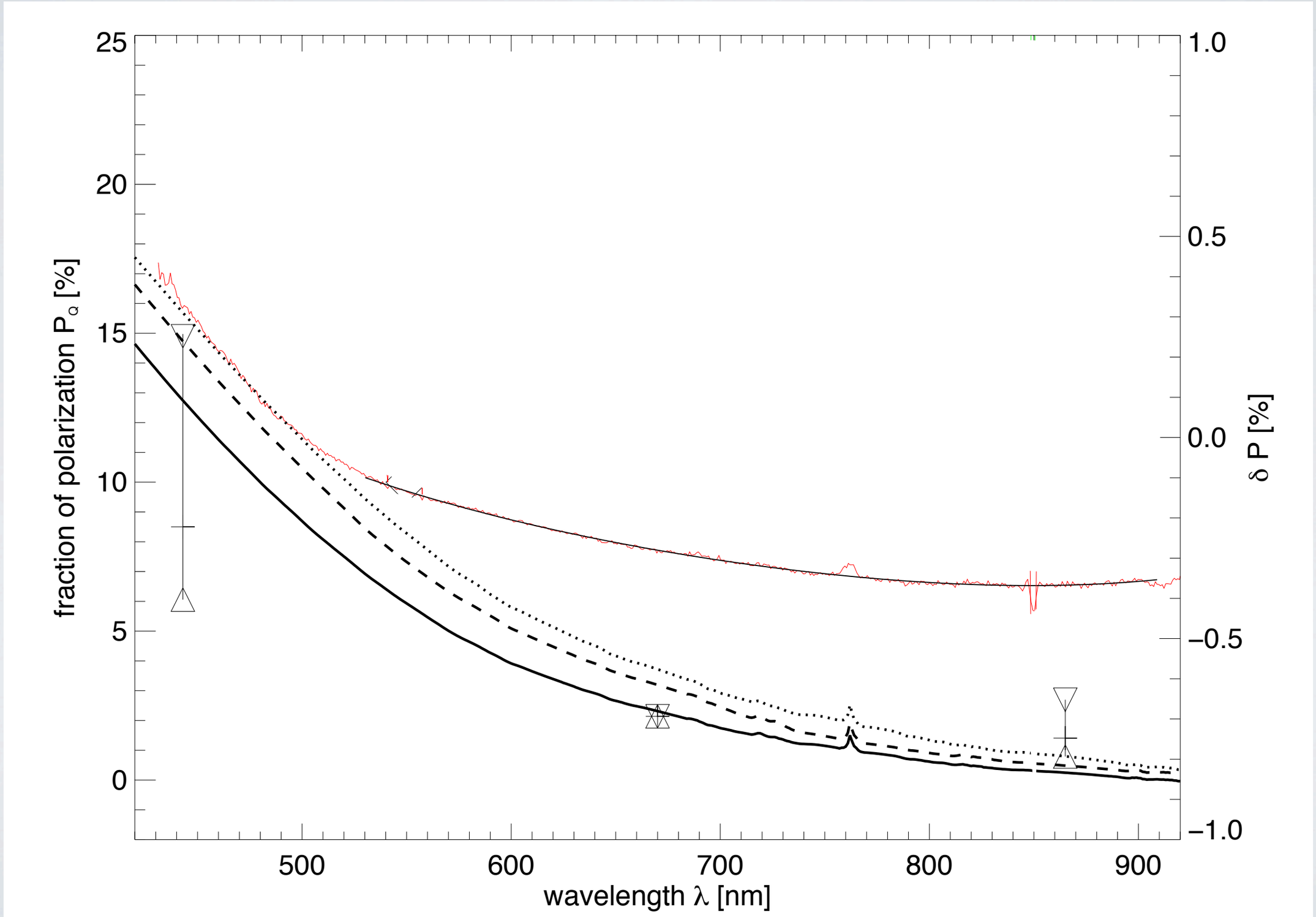
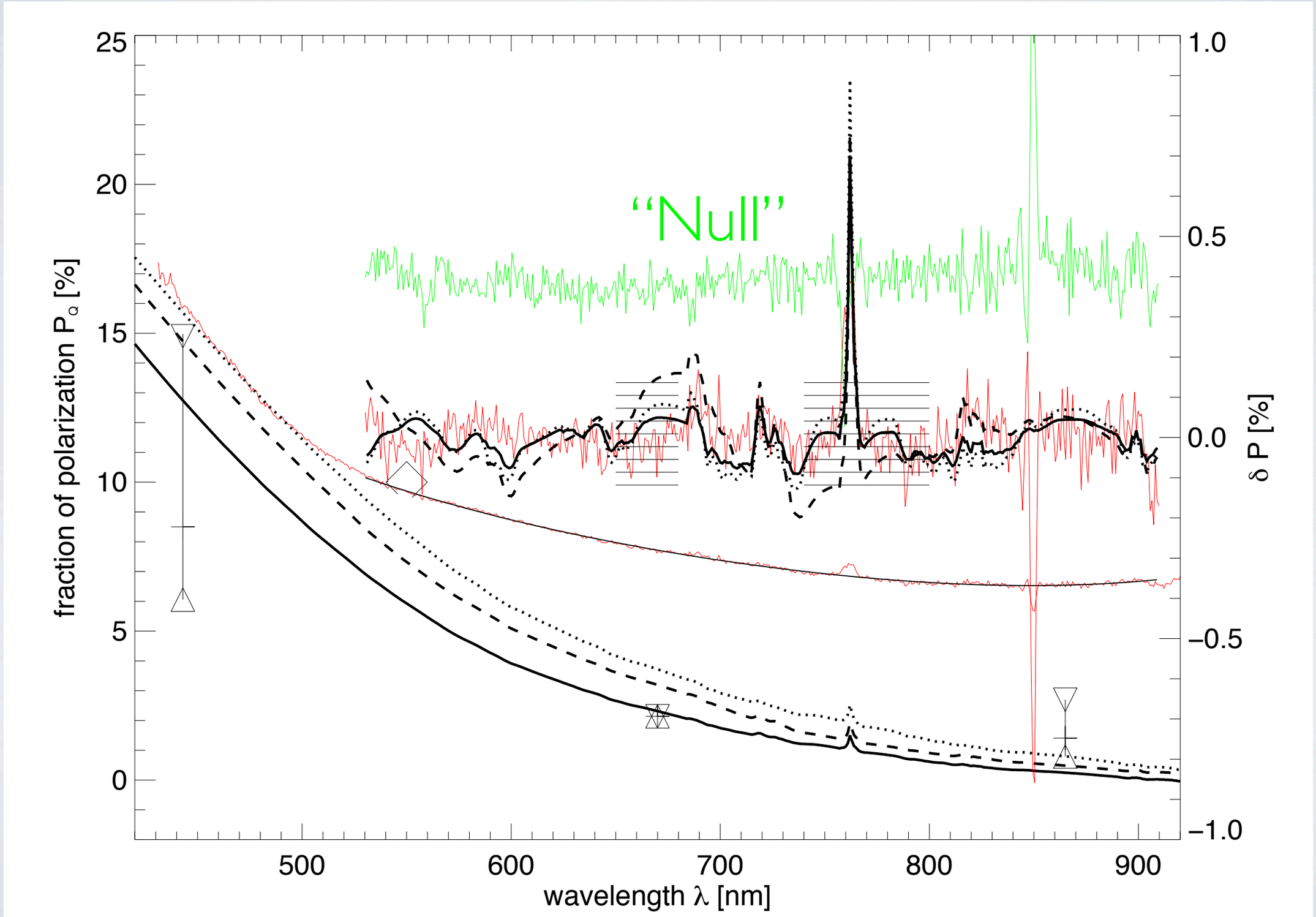


	model	satellite
Clear	73%	50% / 73%(τ<6)
Clouded	27%	50% / 27%(τ>6)

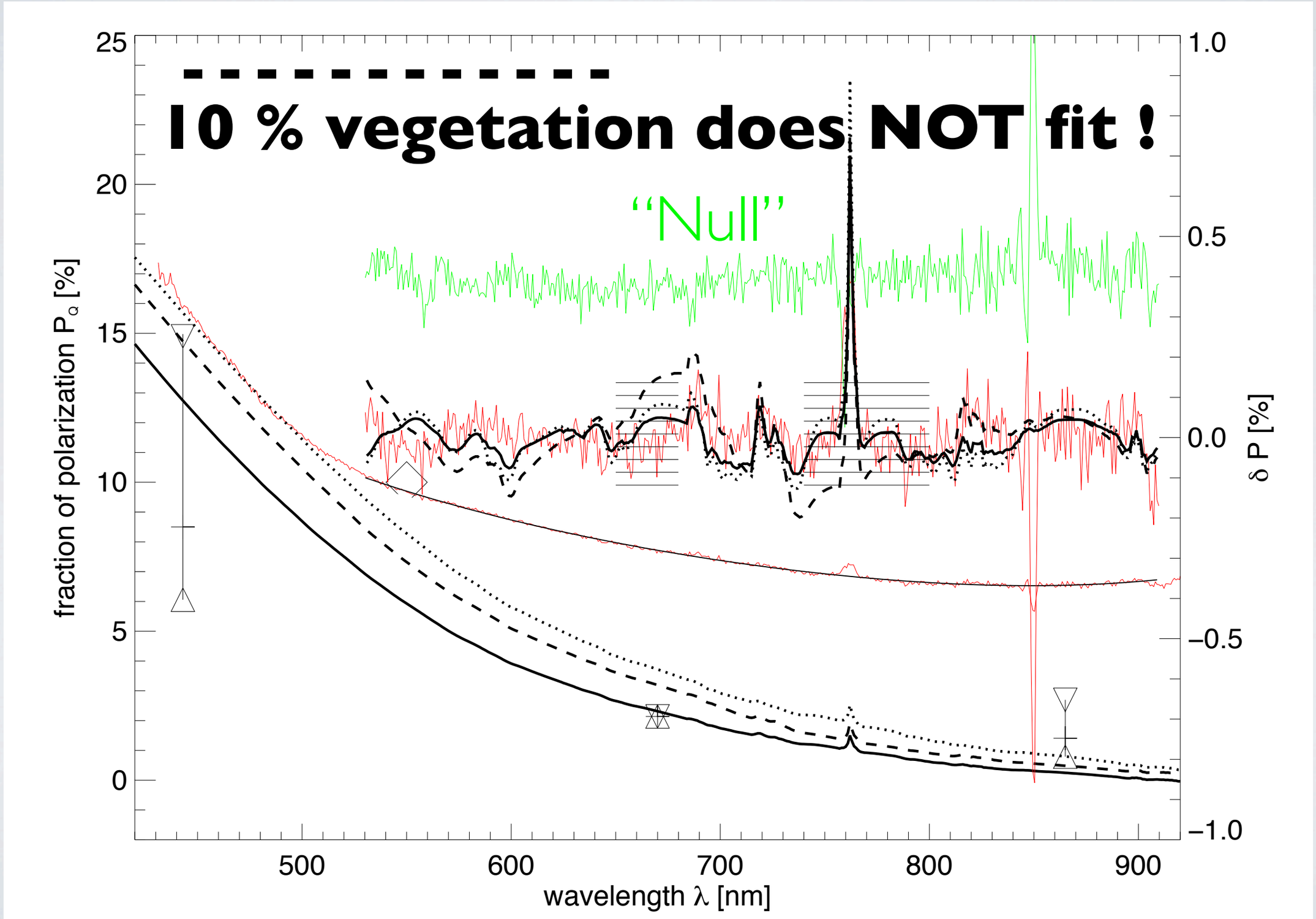
10-Jun-2011:UT01



10-Jun-2011:UT01



10-Jun-2011:UT01



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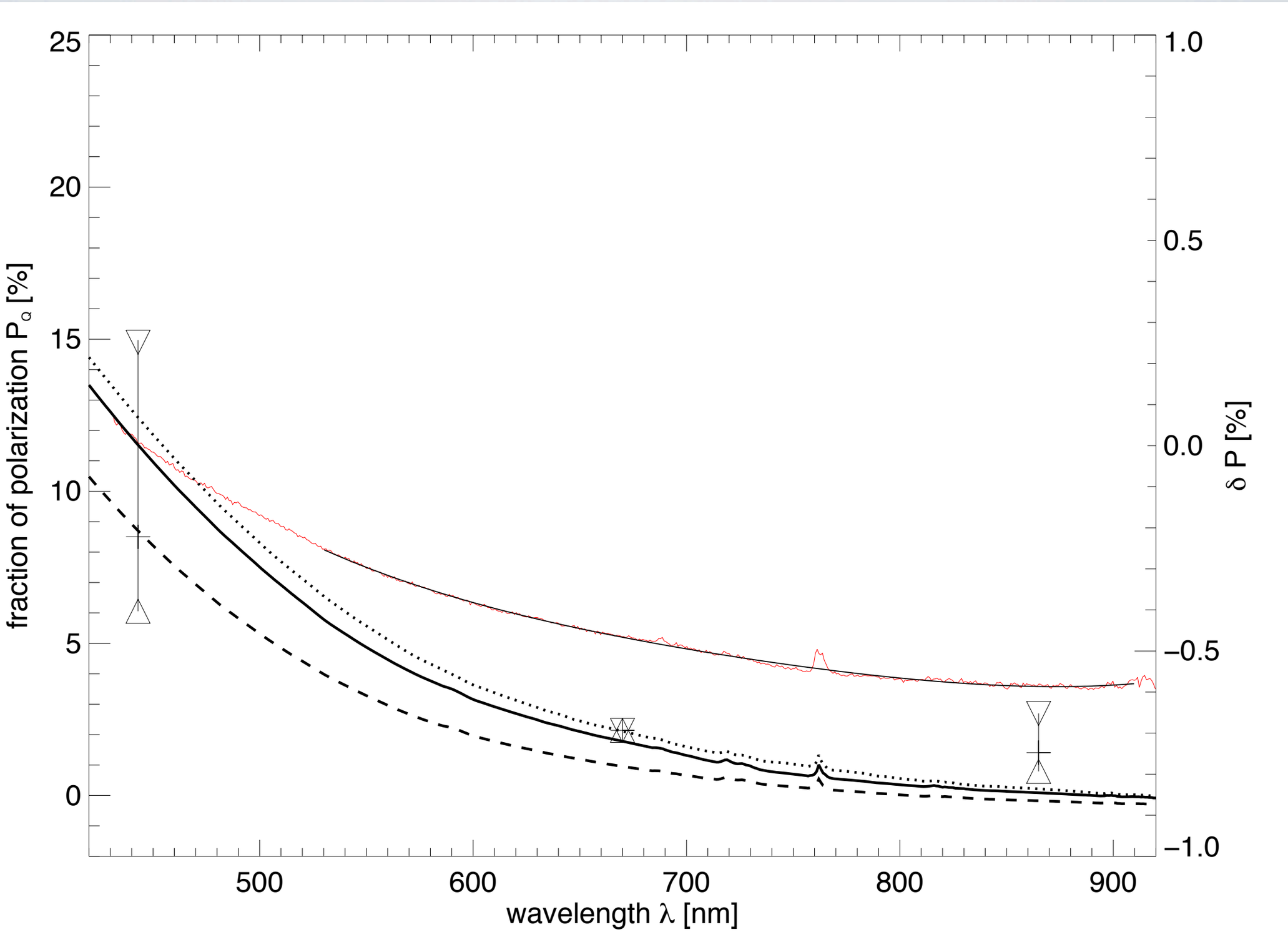

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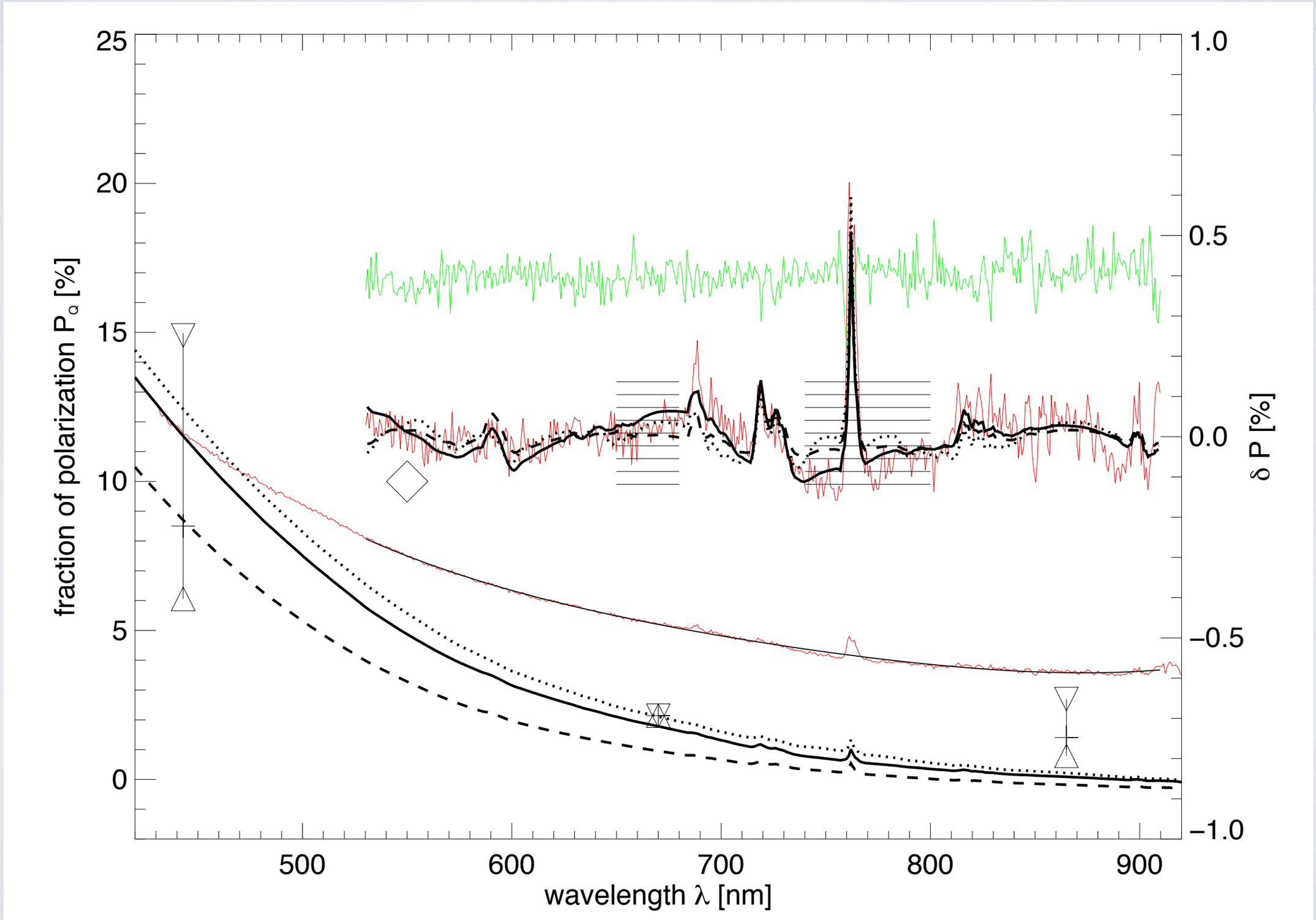

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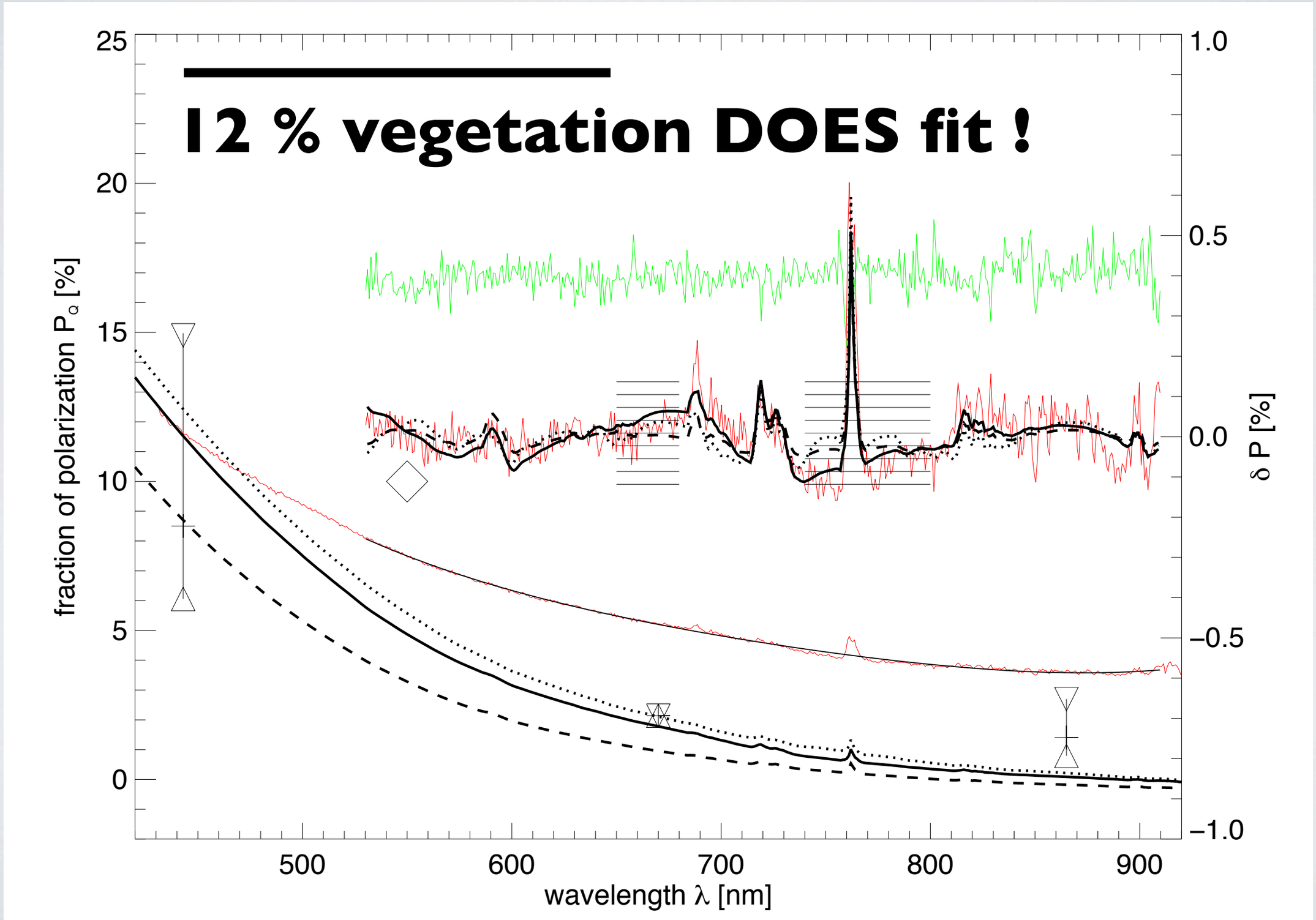


Conclusions

1. Spectropolarimetry(SP) of Earthshine(ES) allows to sensitively constrain Earths surface and atmosphere.

2. Biosignatures can readily be detected in SP@ES.

3. Whole Earth Vector Radiative Transfer (VRT) models require improvement and further validation.

4. Earth global climate and atmosphere models may benefit from systematic SP@ES monitoring.

5. SP@ES + VRT models will feed concept and realization of exo-Life machines.

The Earth In Time

One Month On the Moon

www.sc.eso.org/~msterzik

The Earth In Time

One Month On the Moon

www.sc.eso.org/~msterzik

Caveats

1. Lunar depolarization is not well characterized.

2. Phase-monitoring of the ES is costly (?)

3. What is the relation of Earths biosignatures with exo-biosignatures?

4. Biosignatures on exoplanets are probably not in reach even with the ELT (?)

Polarimetric Signatures of Planets

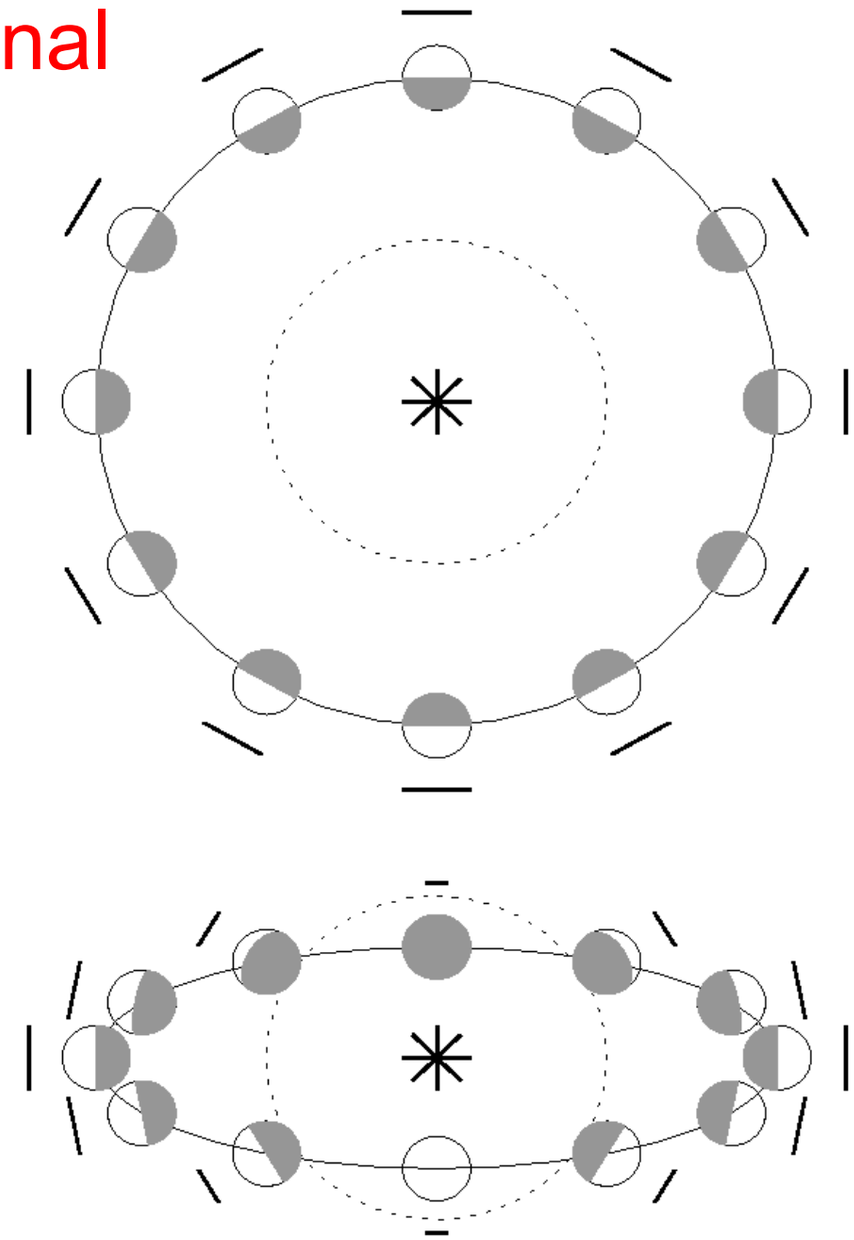
Expected polarization signal

Phase dependence
for Rayleigh-like scattering by
molecules or haze particles

inclination = 0°
- p = constant & high
- θ rotates steadily

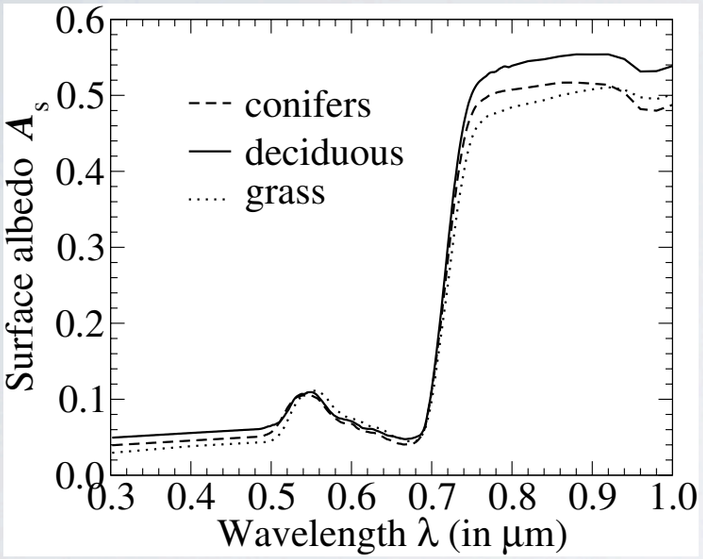
inclination = 70°
- p = high for large separation
- θ fast and slow rotation

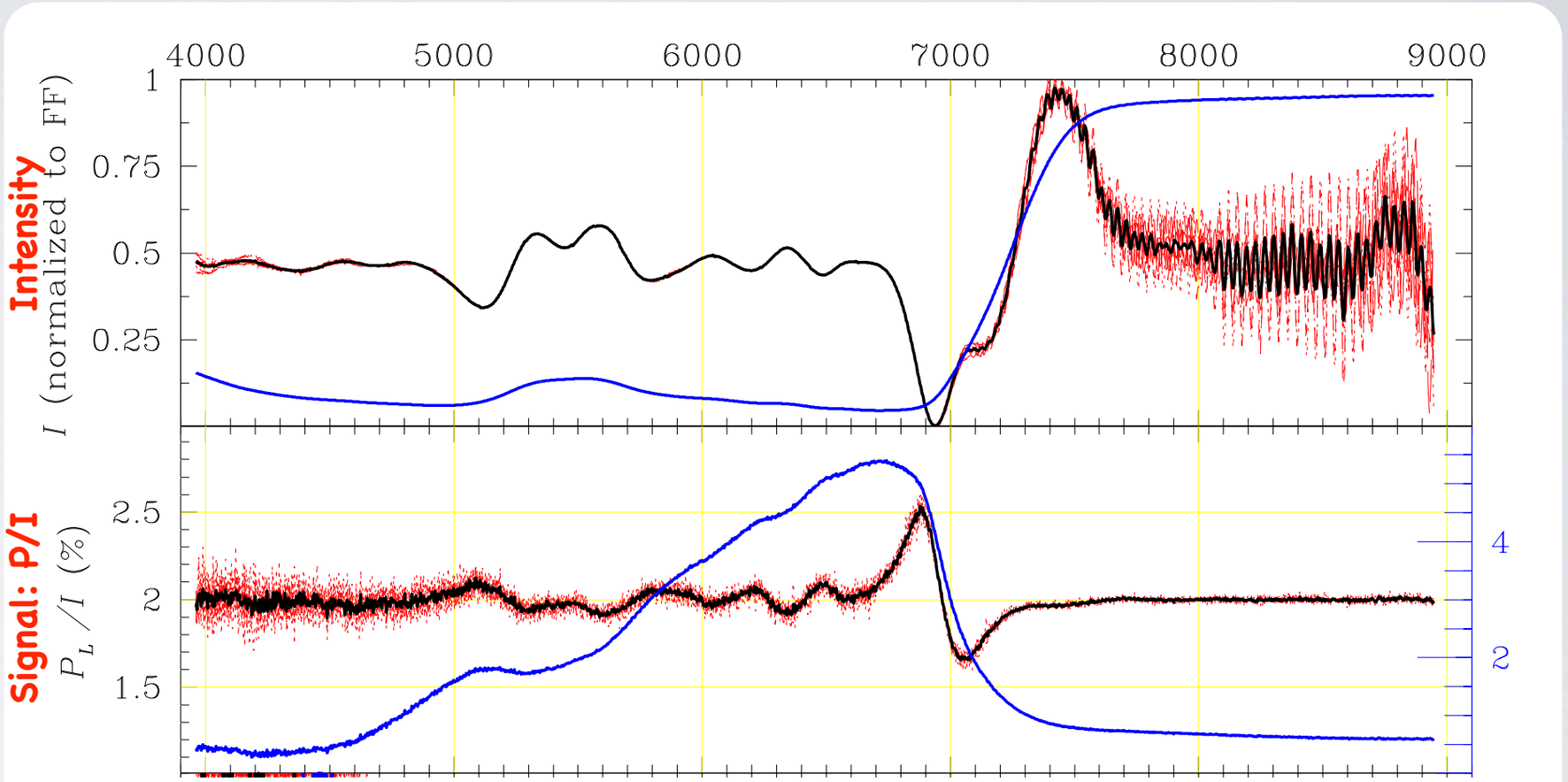
direct light from star is typically unpolarized



Schmidt, H.M., 2010, In the Spirit of Lyot Conference, Paris.

Polarimetric Signatures of Vegetation





Umov effect (P ~ 1/Albedo)

Sterzik, M. *et al.* Astronomy meets biology: EFOSC2 and the chirality of life. *The Messenger* **142**, 25–27 (2010).