

# Spectropolarimetry of Earthshine

A large, dark, cylindrical astronomical instrument is shown in space, with a bright sun in the lower right corner and a starry background. The instrument has several smaller components attached to its side.

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D. Stam, TU Delft

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**50 BILD-Reporter sagen, wen sie NICHT wählen!**

Morgen ist Wahltag: 40 Millionen Deutsche sind aufgerufen, ihre Stimme abzugeben. Die meisten

wissen schon, wen sie wählen. In DZD sagen 50 Reporter: Wen sie **NICHT** wählen wollen. S. 2

**Forscher veröffentlichen Foto-Beweis**



Dieses Foto aus dem Elektronen-Mikroskop legt nahe, dass der organische (lebende) Teilchen aus dem All

# Leben im All entdeckt!

**Genuss zeigt Wirkung.**



Samstag, 21. September 2013 0,70 €



**BILD CITY**

**Alles drin!**

IMMUNANGLIO - ÜBERPARTeilICH

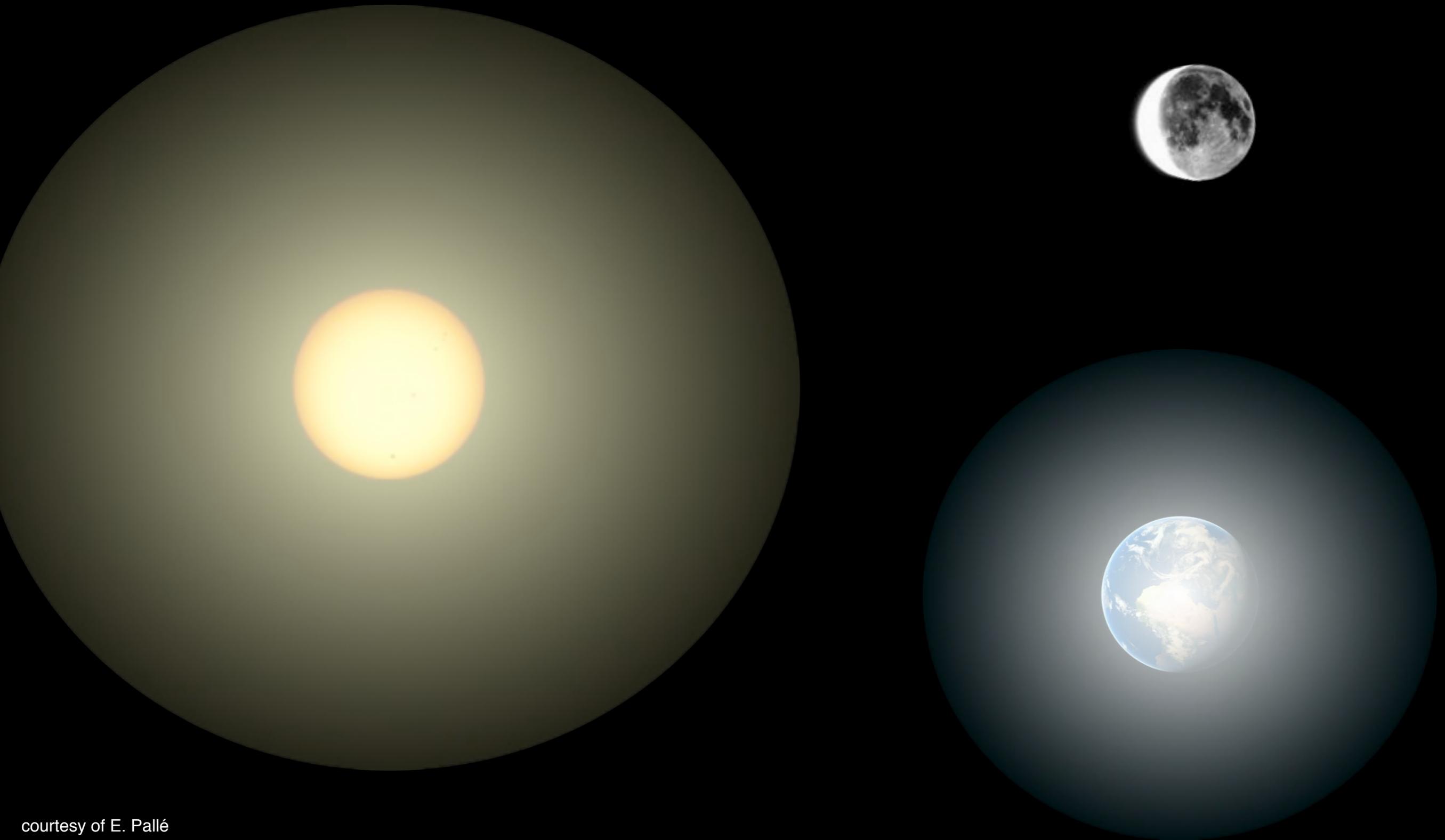
**Klum-Model liebt Skandal-Fußballer**  
Gladbach - Braunschweig 4:1



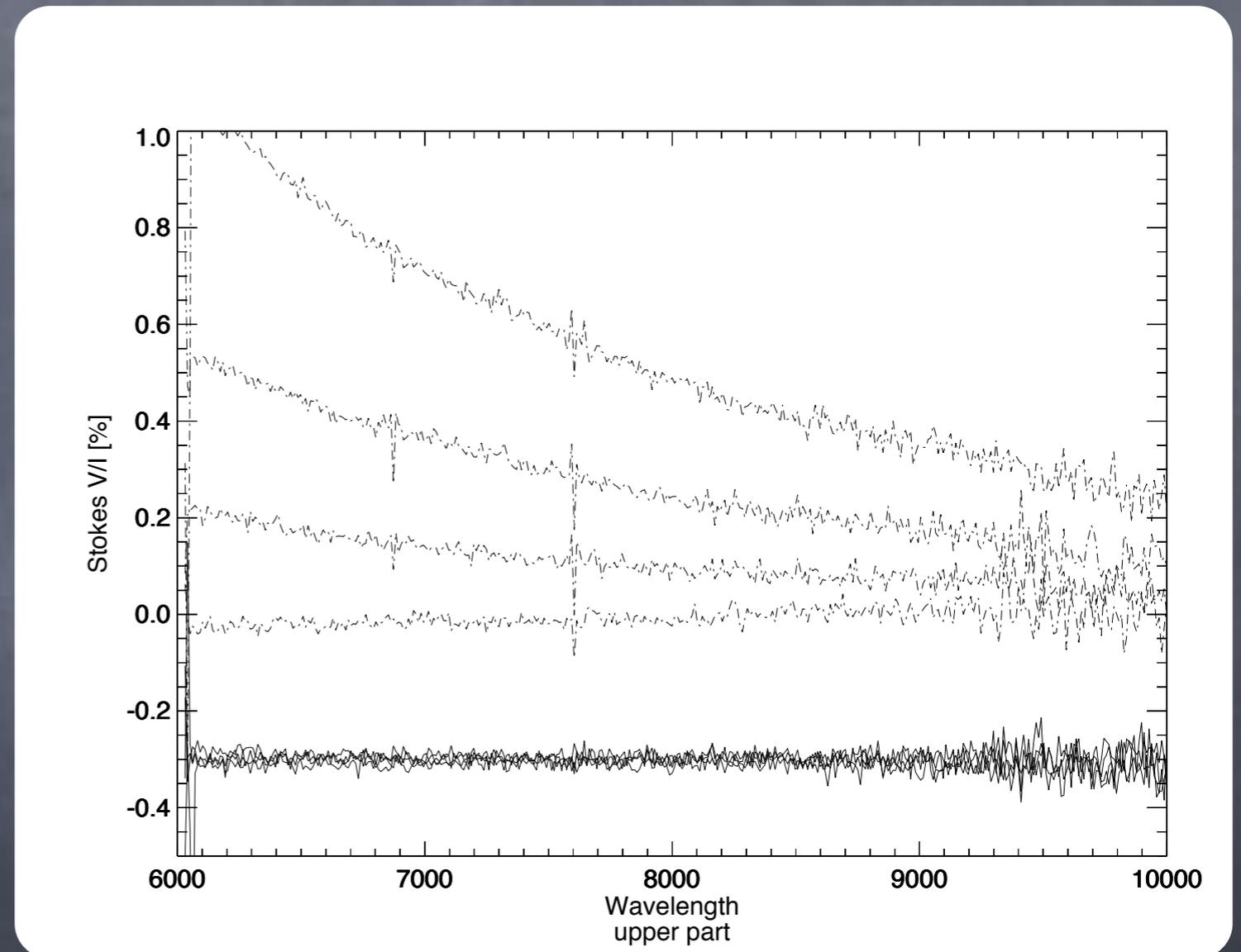
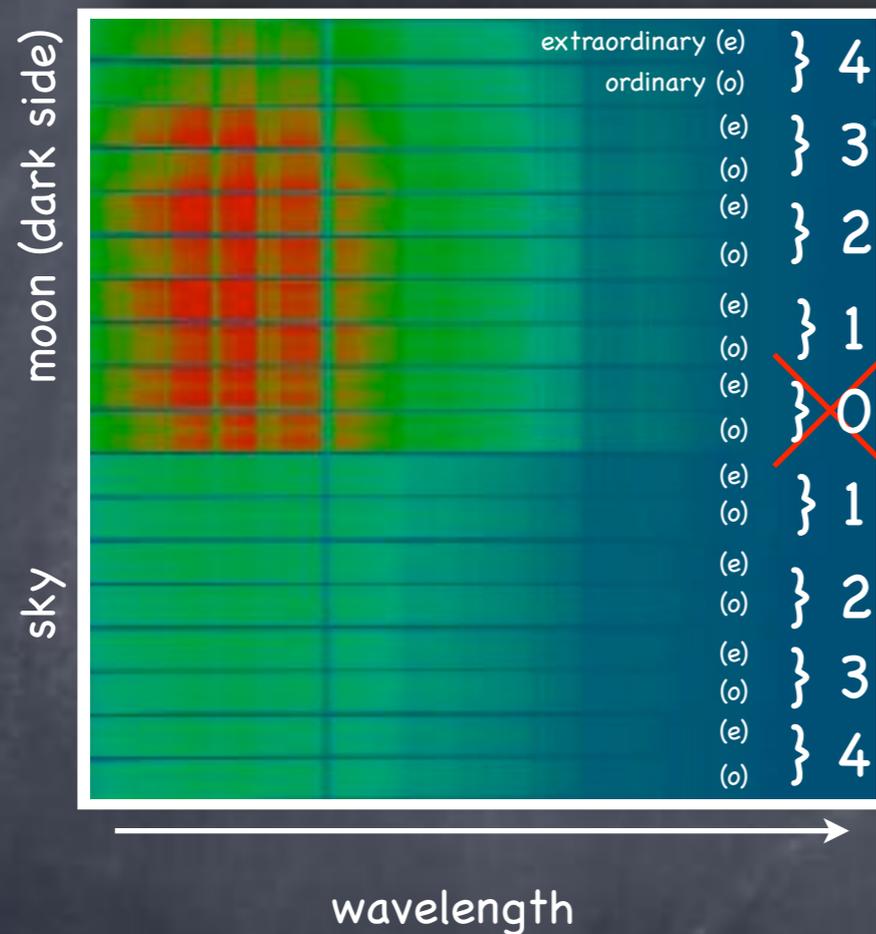
# Observation of Earth. From Earth.



# Earthshine reflects



# Spectropolarimetry of ES: The Saga part I (2006)



instead of re-covering chiral signatures in ES...

# ... we found Instrument X-talk

... prompted its own study ...

X-talk caused by birefringence of the collimator lens

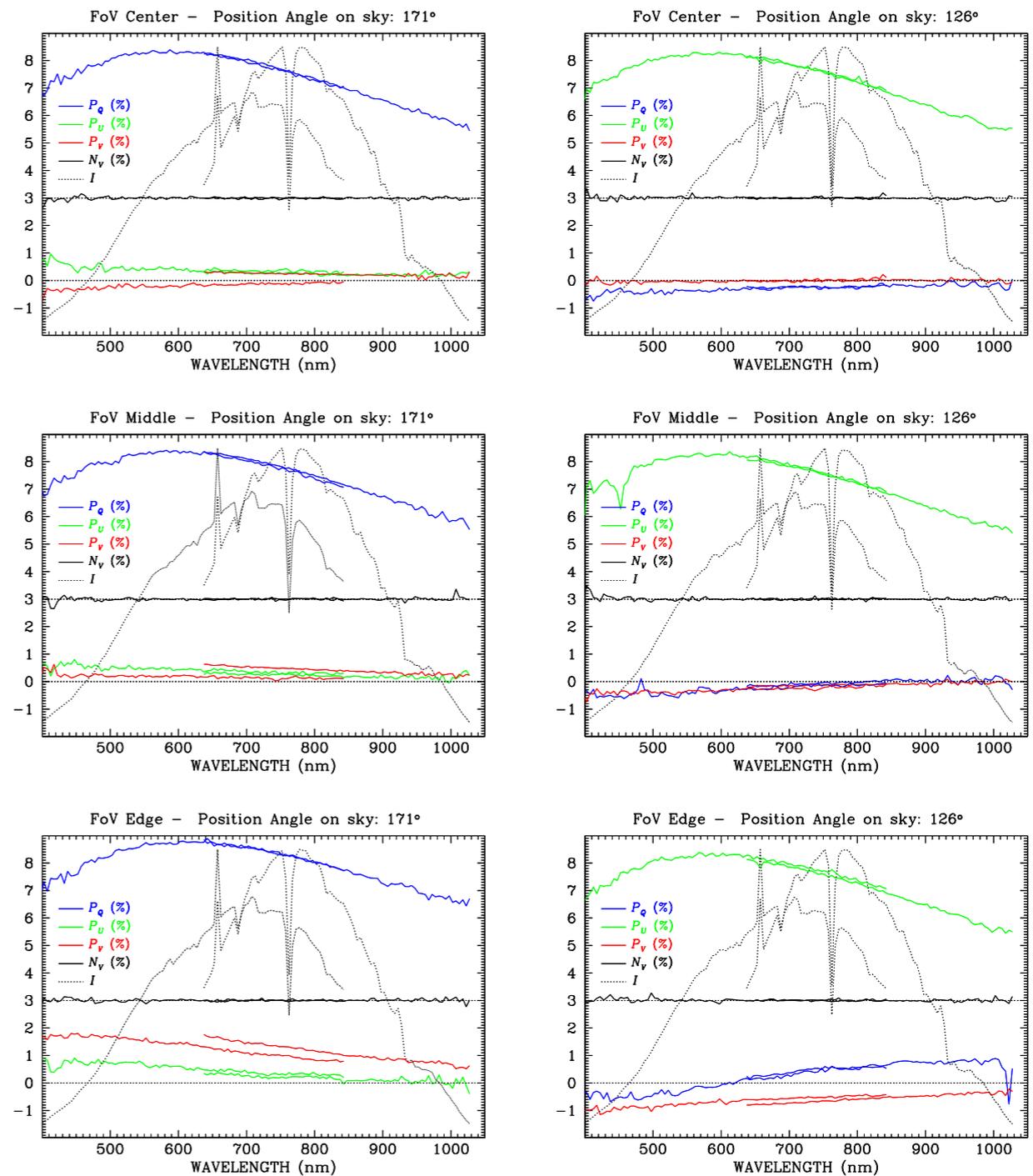
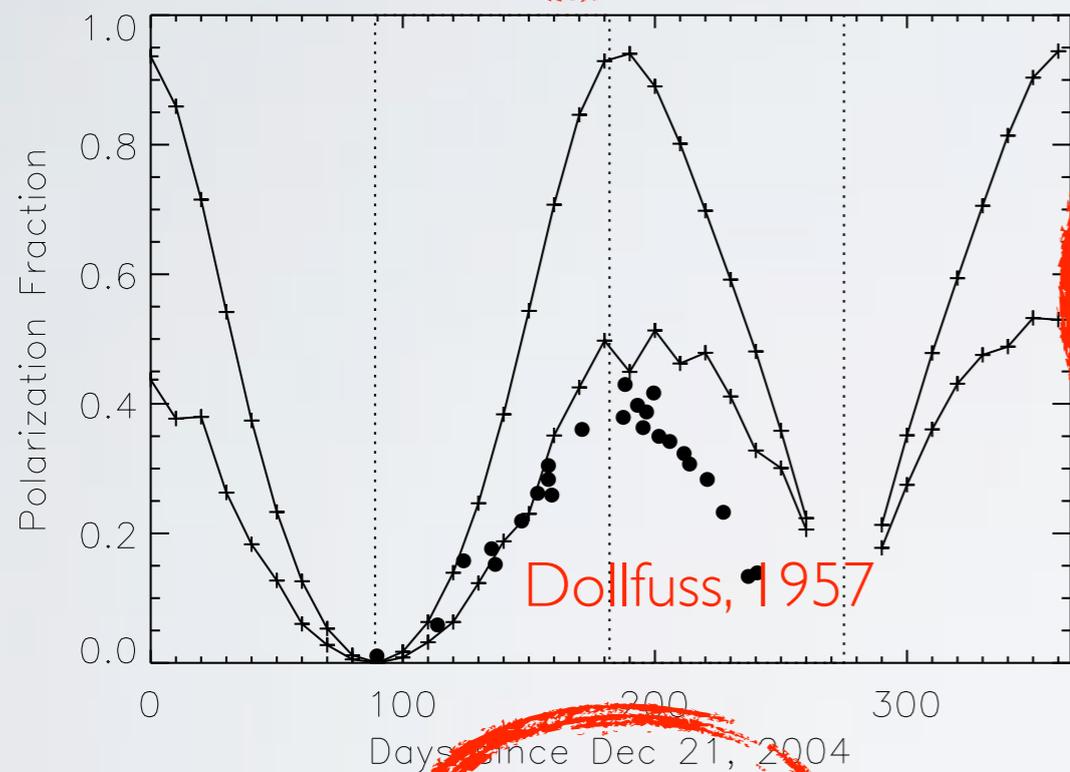


Fig. 10.— Observations of linear and circular polarization of Ve-6-23 obtained with grisms 300 V and 300 I at different positions of the FoV and different values of the instrument position angle, as indicated at the top of each panel. Different lines represent  $P_Q$  (blue),  $P_U$  (green),  $P_V$  (red), expressed in %, and Stokes  $I$  (dotted lines, in arbitrary units). The null spectra  $N_V$  (black solid lines) are also expressed in %, and offset by +3% for display purpose.

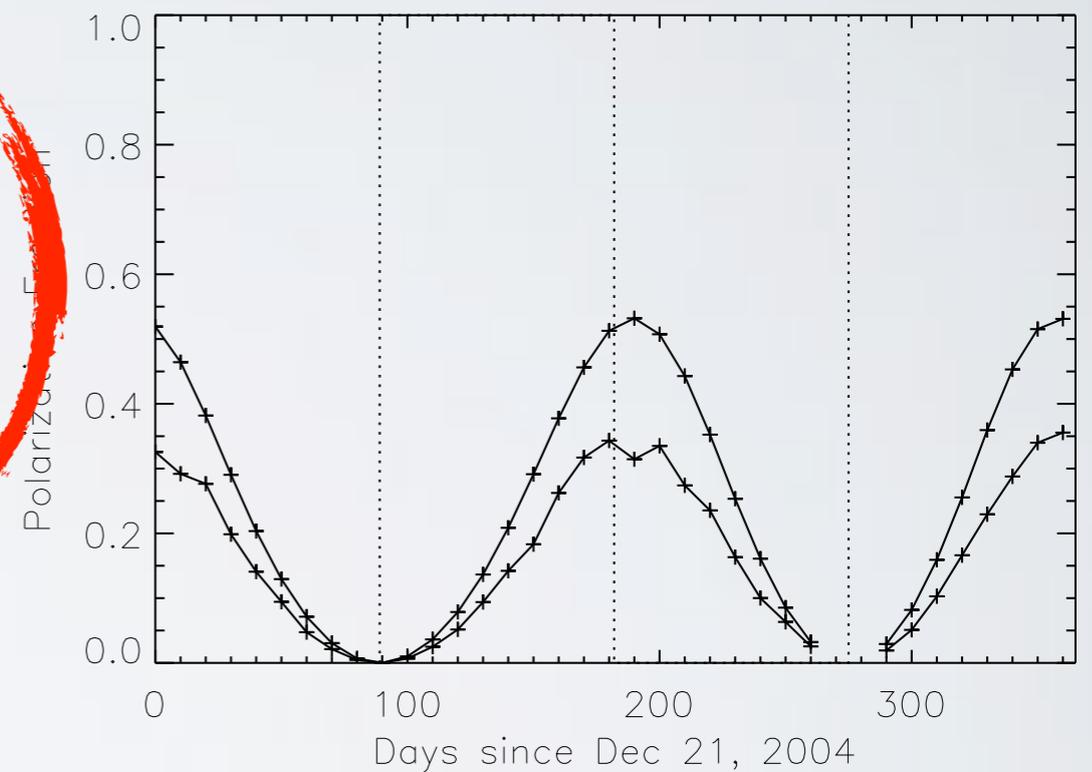
# Polarimetric Signatures of Planet Earth

pure ocean surface



Phase Angle

pure land surface



Phase Angle

no clouds

clouds

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

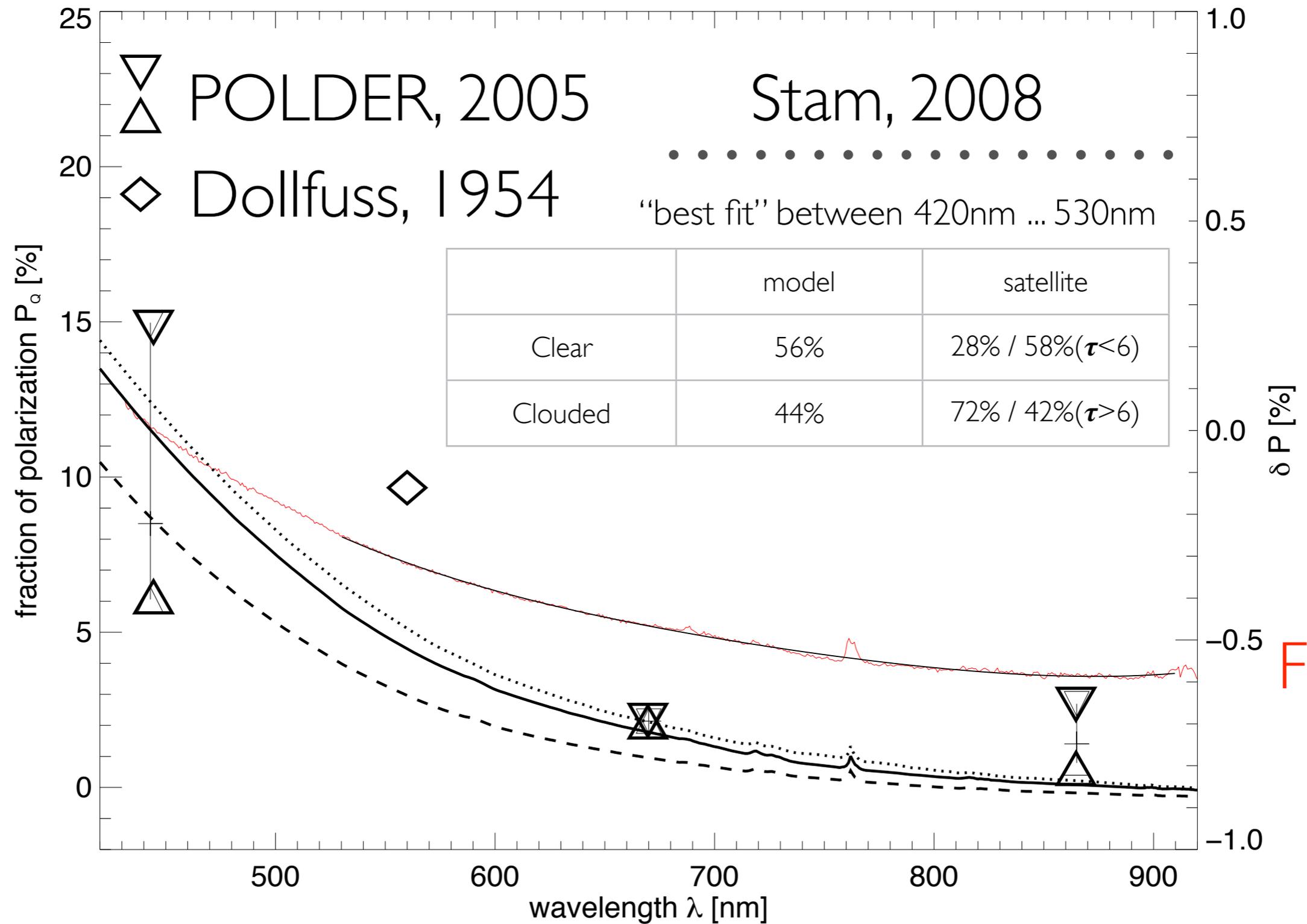
Williams, D. M. & Gaidos, E. Detecting the glint of starlight on the oceans of distant planets. *Icarus* **195**, 927–937 (2008).

# Spectropolarimetry of ES: The Saga part II (2011/12)

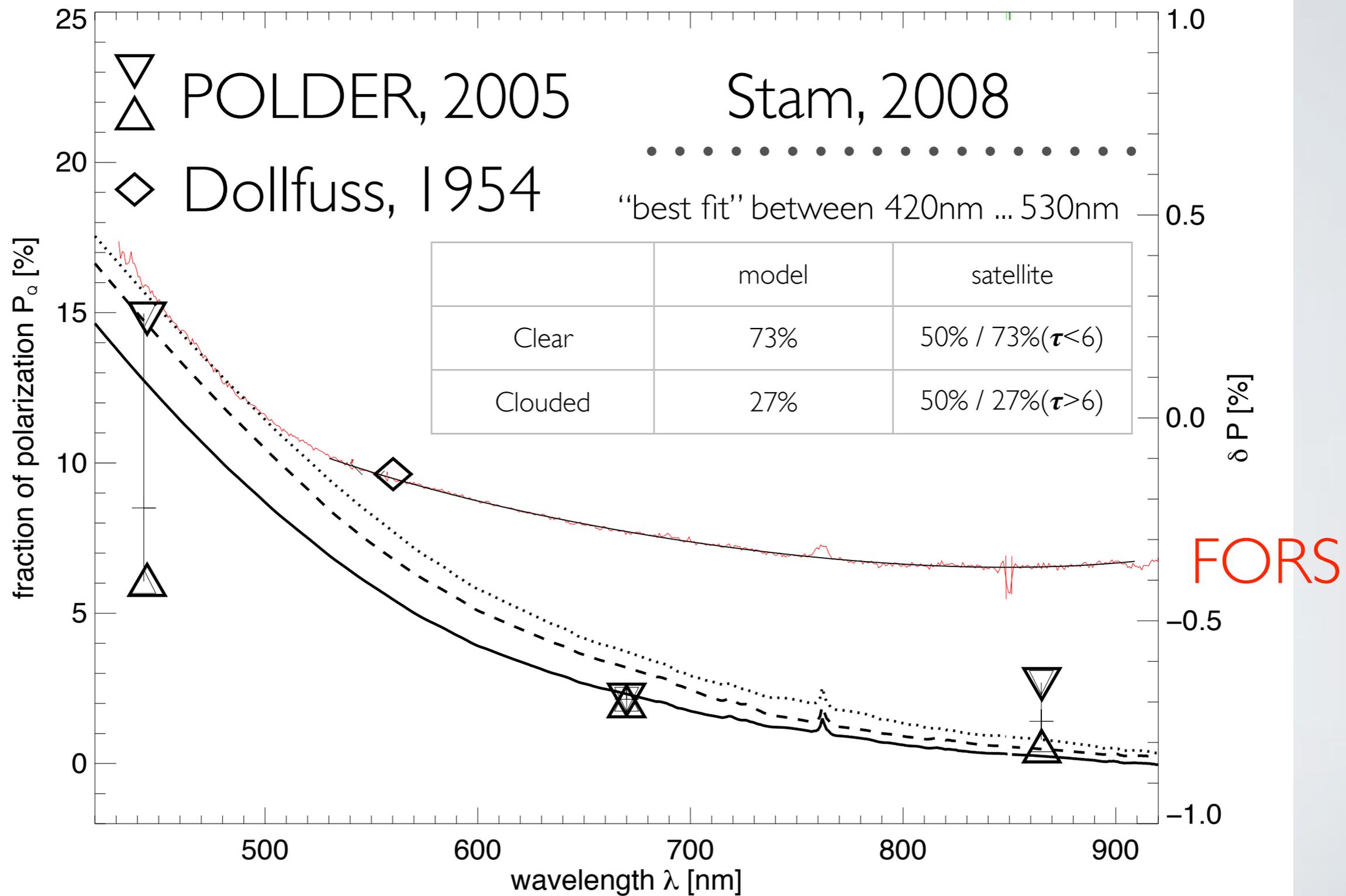
Observing Date	25-Apr-2011:UT09	10-Jun-2011:UT01
View of Earth as seen from the Moon		
Sun-Earth-Moon phase	87 deg	102 deg
ocean fraction in Earthshine	18%	46%
vegetation fraction in Earthshine	7%	2%
tundra, shrub, ice and desert fraction in Earthshine	3%	1%
total cloud fraction in Earthshine	72%	50%
cloud fraction $\tau > 6$	42%	27%

*Earth's aspect changes...*

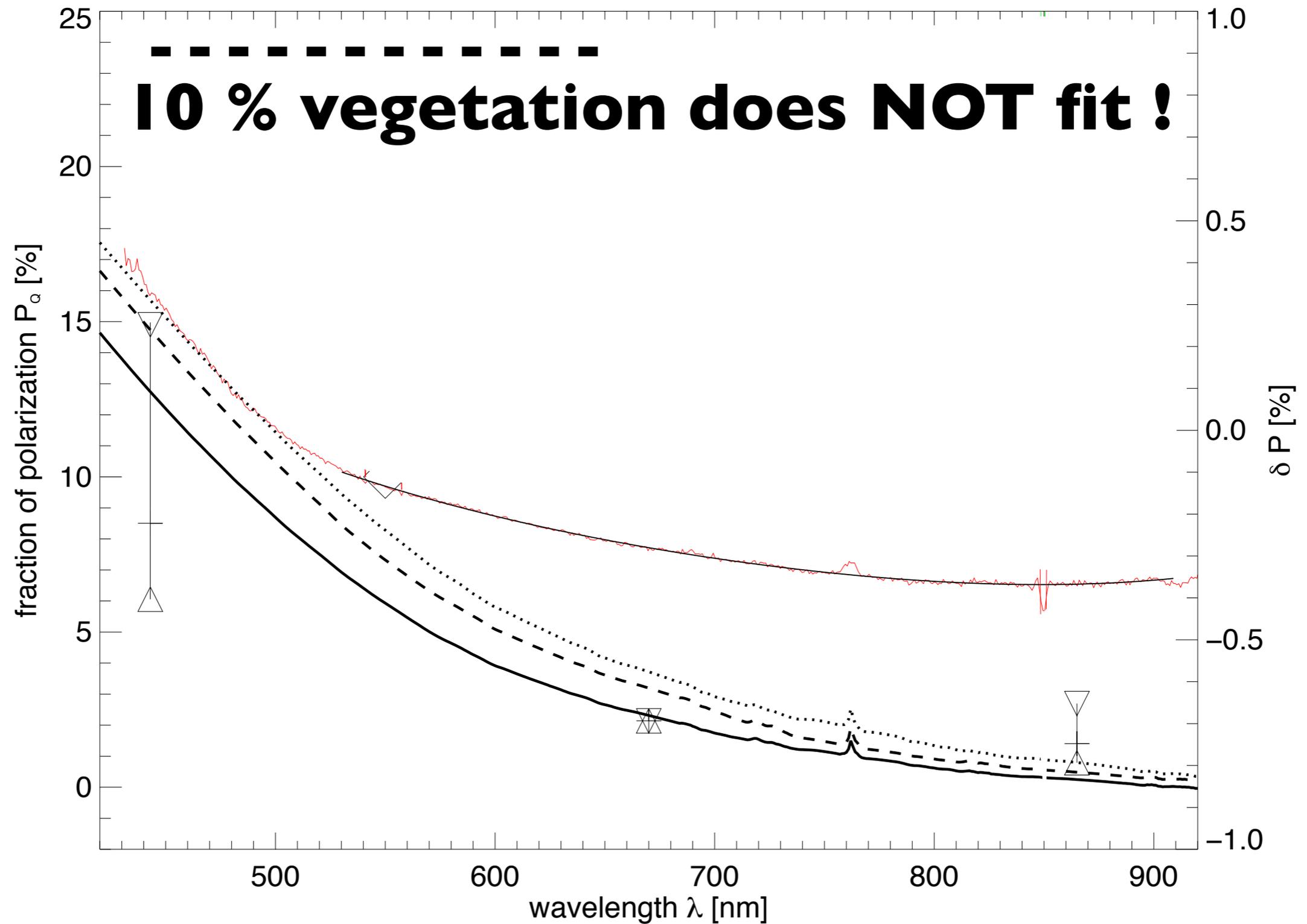
# 25-Apr-2011:UT09



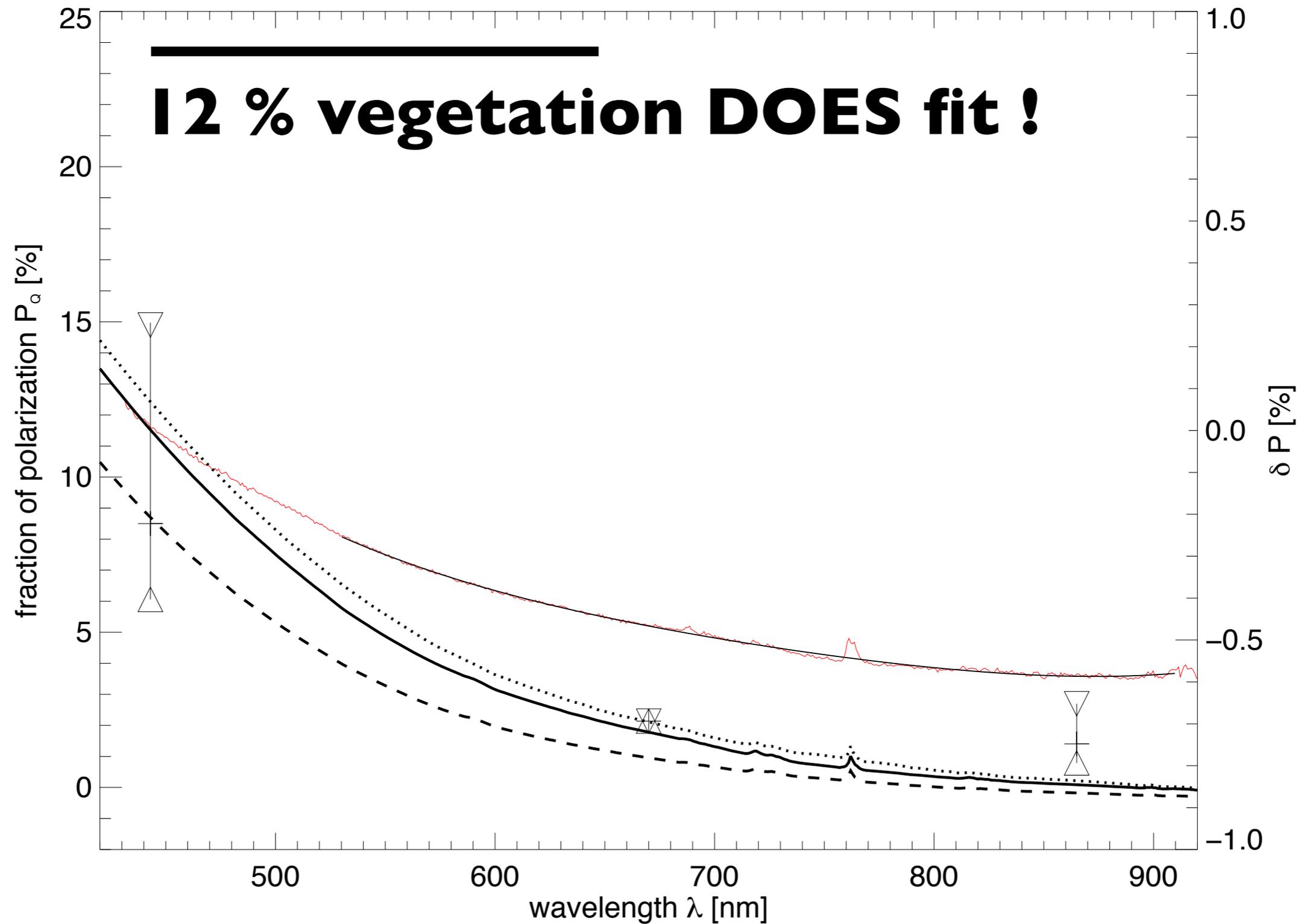
# 10-Jun-2011:UT01



10-Jun-2011:UT01



25-Apr-2011:UT09



# Lunar Depolarization

– Dollfuss

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).

– We used some flavor of Fox et al.

## 3.2 Depolarization factor

A simple model that has been used successfully to explain the polarization of solid bodies is the puka (pit) model by Steigmann (1978). Steigmann (1978) showed that for a Fresnel reflecting surface, when only single or double scattering is important, the polarization could be written in the form of

$$P = \frac{P(V)}{1 + R_2 \left(\frac{\lambda}{\lambda_0}\right)^q} = \frac{P(V)}{1 + \left(\frac{\lambda}{\lambda_1}\right)^q}, \quad (5)$$

Fox, G. *et al.* Solar system observations by the Wisconsin Ultraviolet Photopolarimeter Experiment–III. The first ultraviolet linear spectropolarimetry of the Moon. *Monthly Notices of the Royal Astronomical Society* 298, 303–309 (1998).

– Bazzon et al.

efficiency  $\log \epsilon$  as function of  $\log a_{603}$ , the albedo at 603 nm, and  $\log \lambda$  for the wavelength

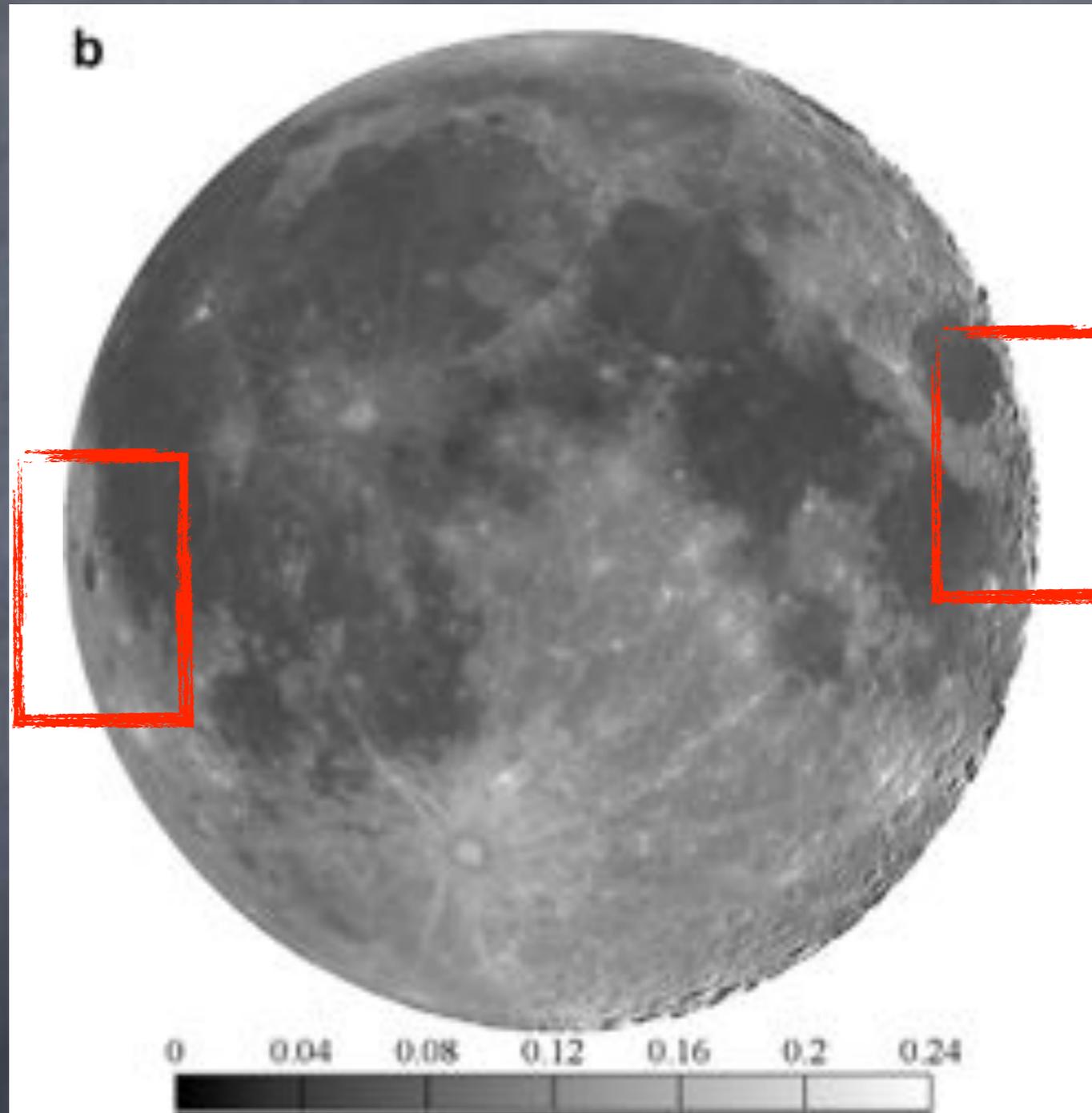
$$\log \epsilon(\lambda, a_{603}) = -0.61 \log a_{603} - 0.291 \log \lambda[\mu\text{m}] - 0.955. \quad (9)$$

Bazzon, A., Schmid, H. M. & Gisler, D. Measurement of the earthshine polarization in the B, V, R, and I band as function of phase. *A&A* 556, 117-131 (2013).

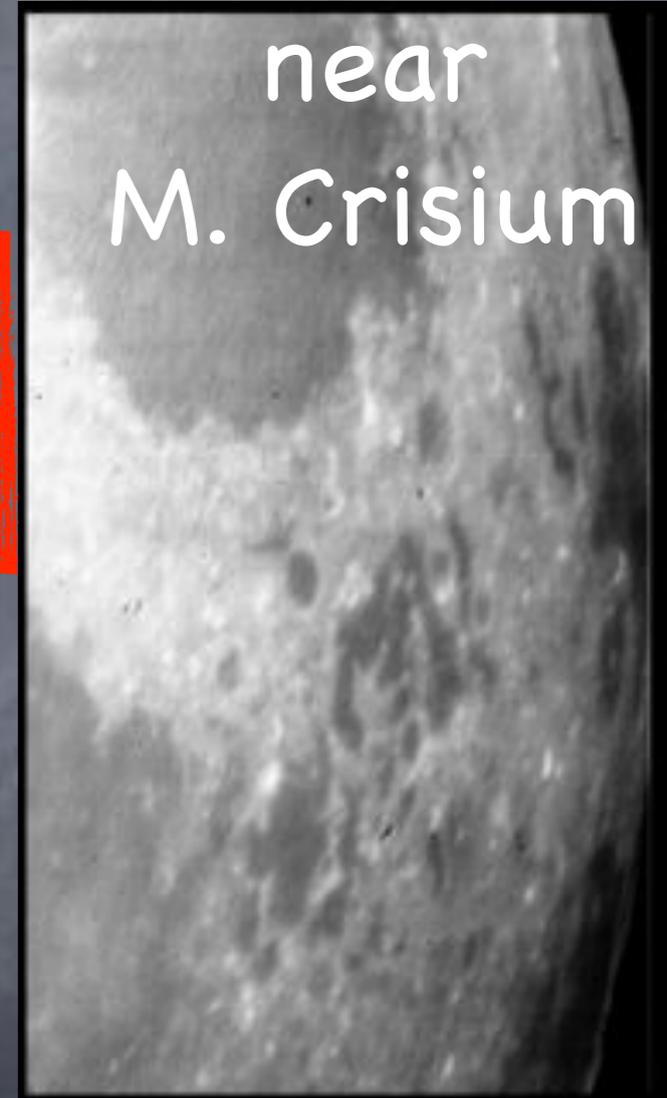
# Backscatter on the Moon



FORS1 acq image  
26-Nov-2006:UT00



**Fig. 5.** Apparent albedo (a) and equigonal albedo (b) maps for phase angle  $22.2^\circ$  and wavelength 603 nm.

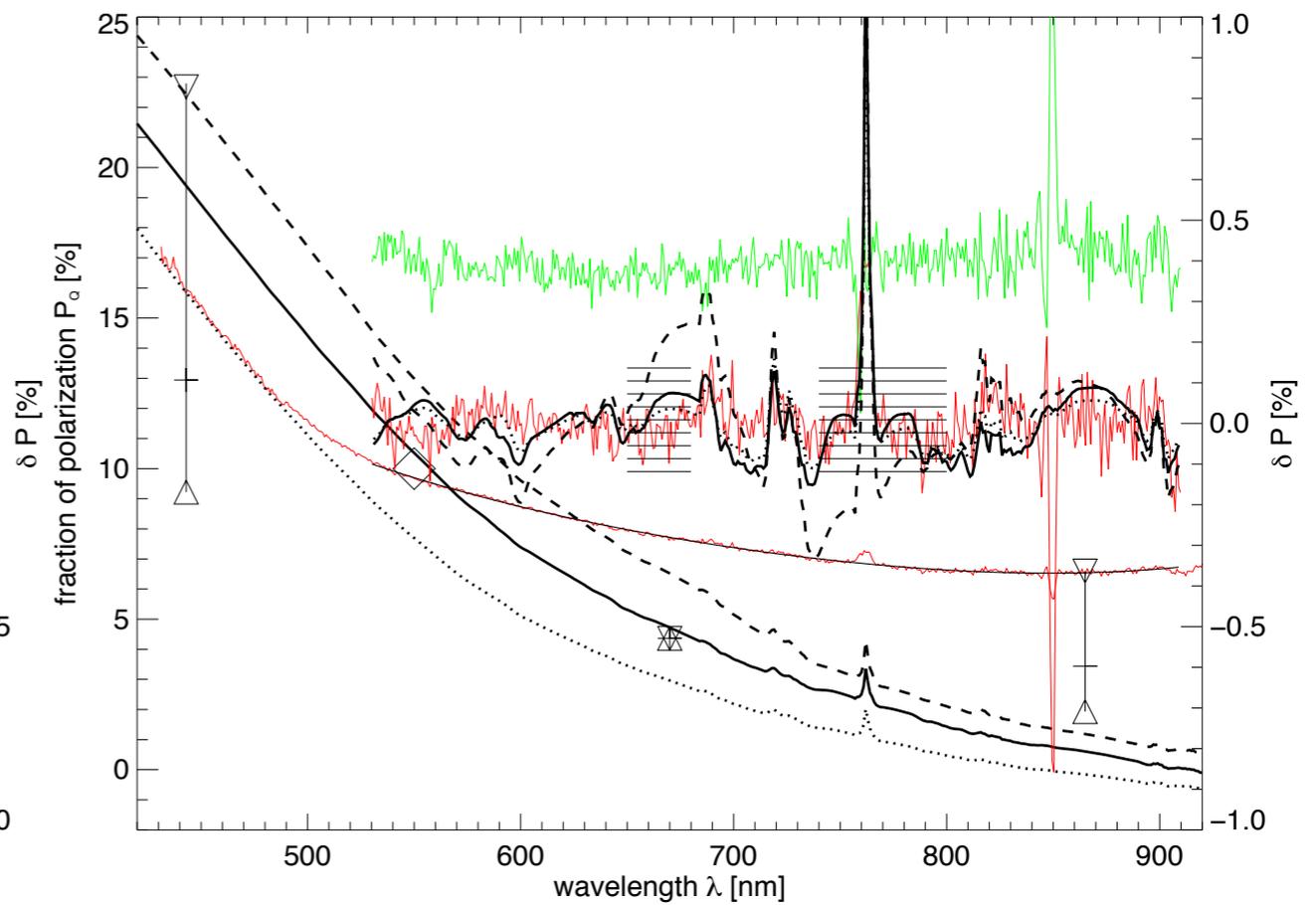
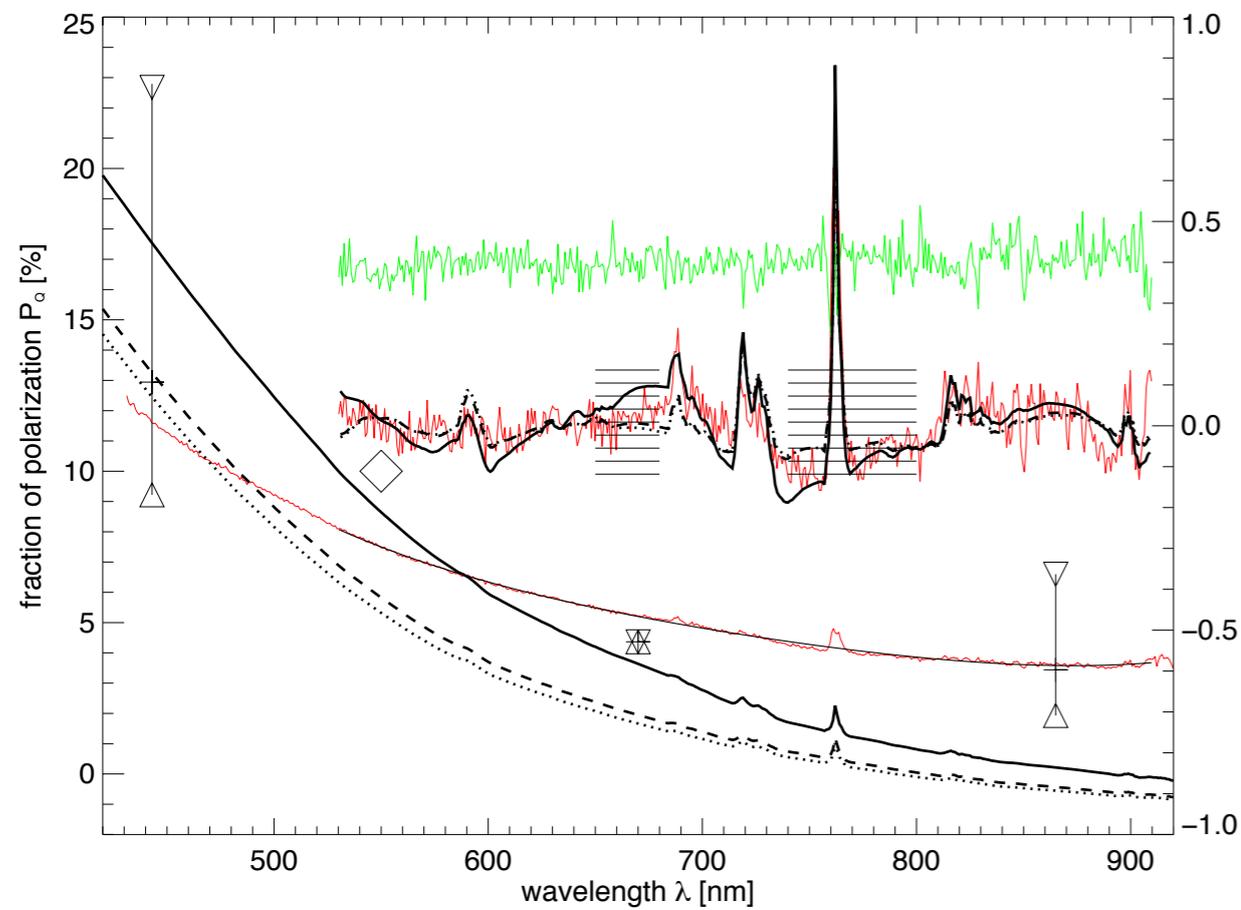


FORS2 acq image  
25-Apr-2011:UT09

# Impact on Earthshine SP

25-Apr-2011:UT09

10-Jun-2011:UT01



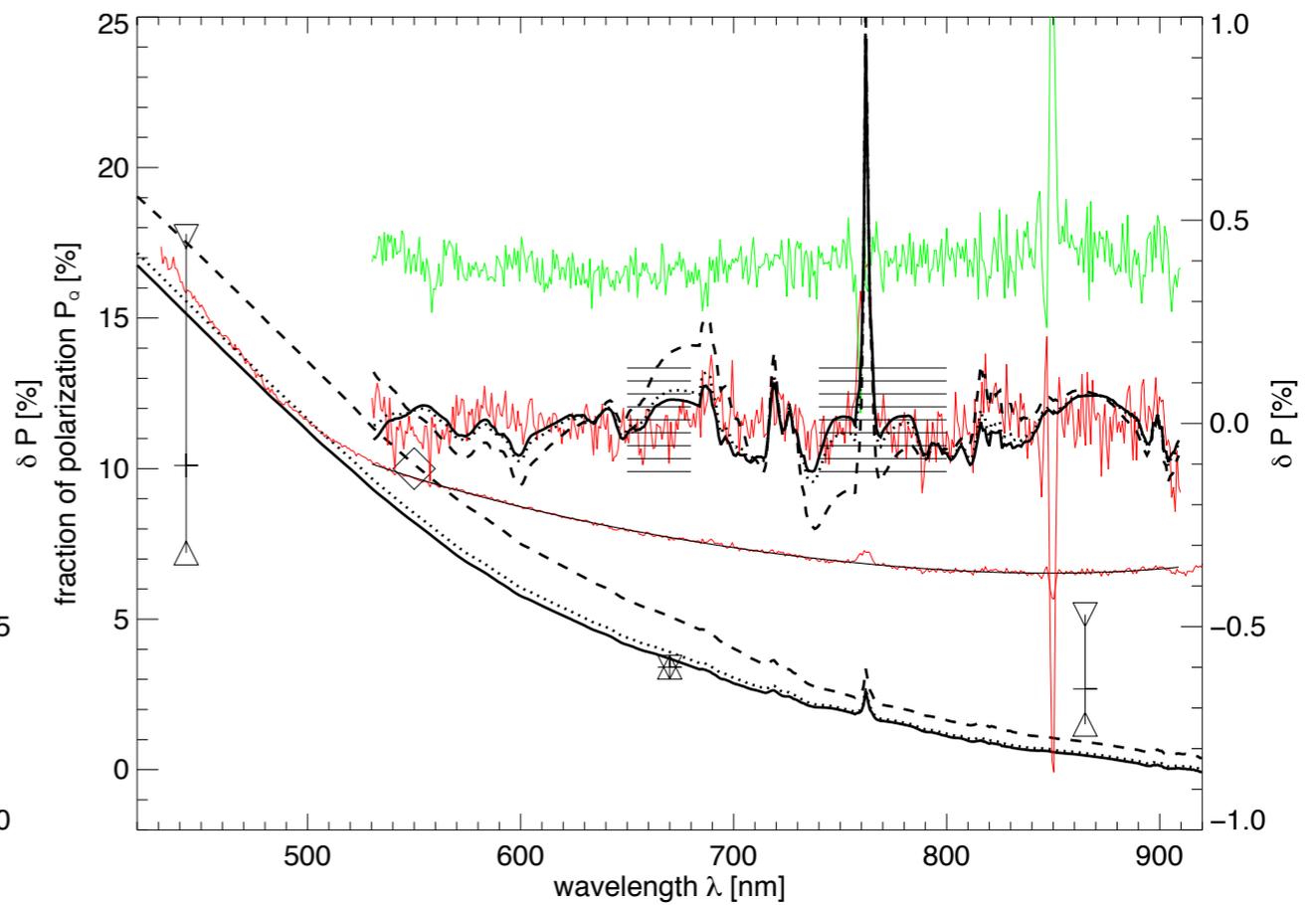
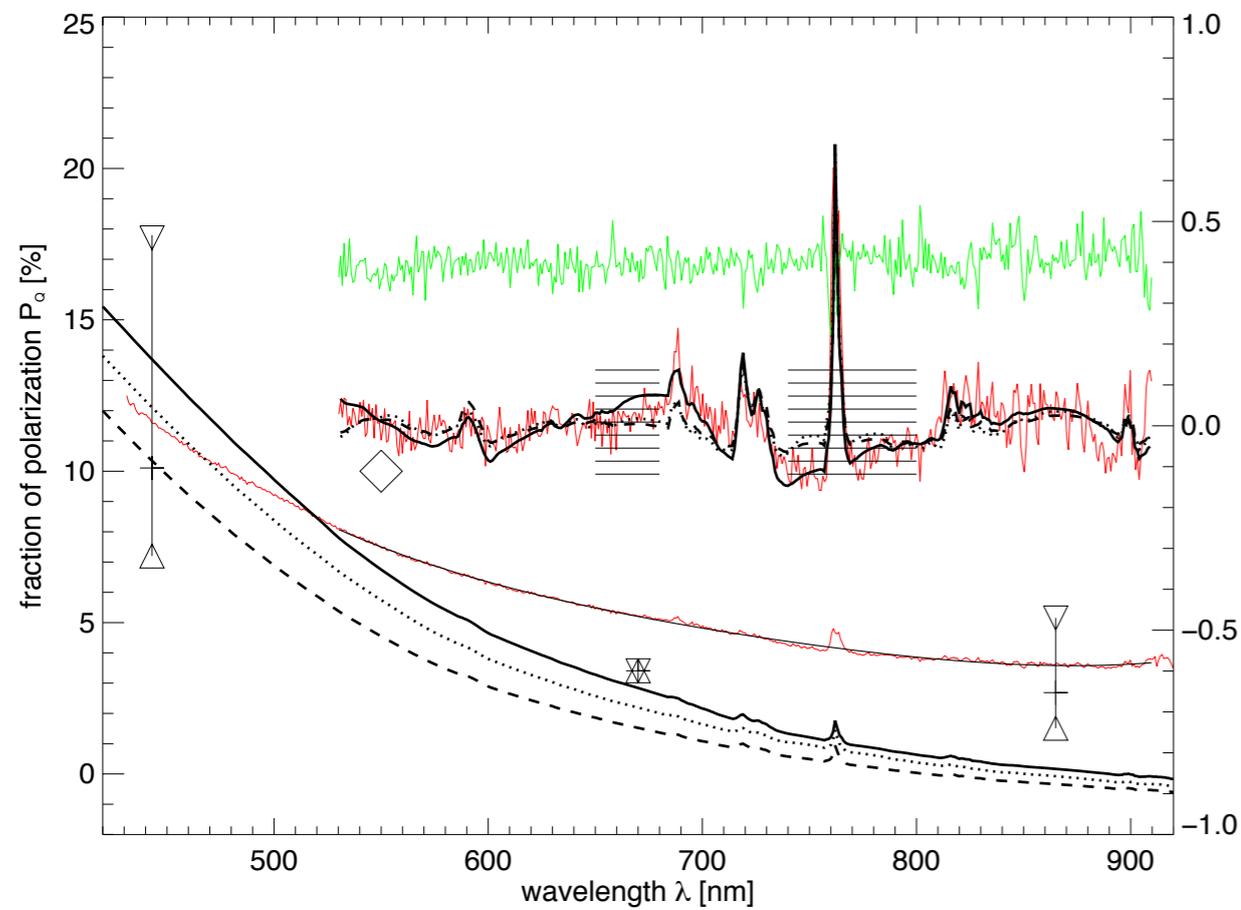
actual cloud cover: 42% ... 72%  
BSG model w/  $A=0.1$  75%

actual cloud cover: 27% ... 50%  
BSG model w/  $A=0.1$  54%

# Impact on Earthshine SP

25-Apr-2011:UT09

10-Jun-2011:UT01



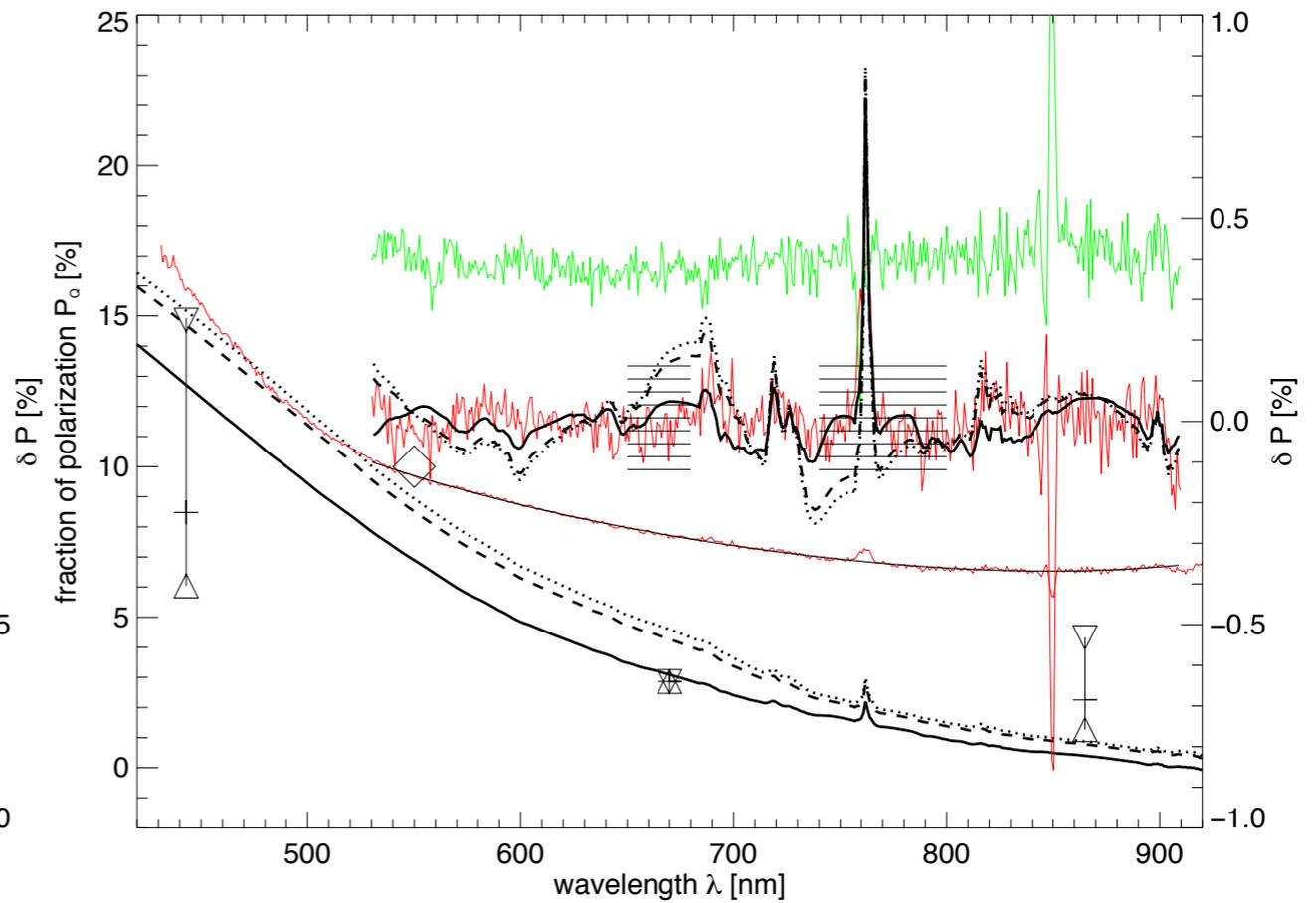
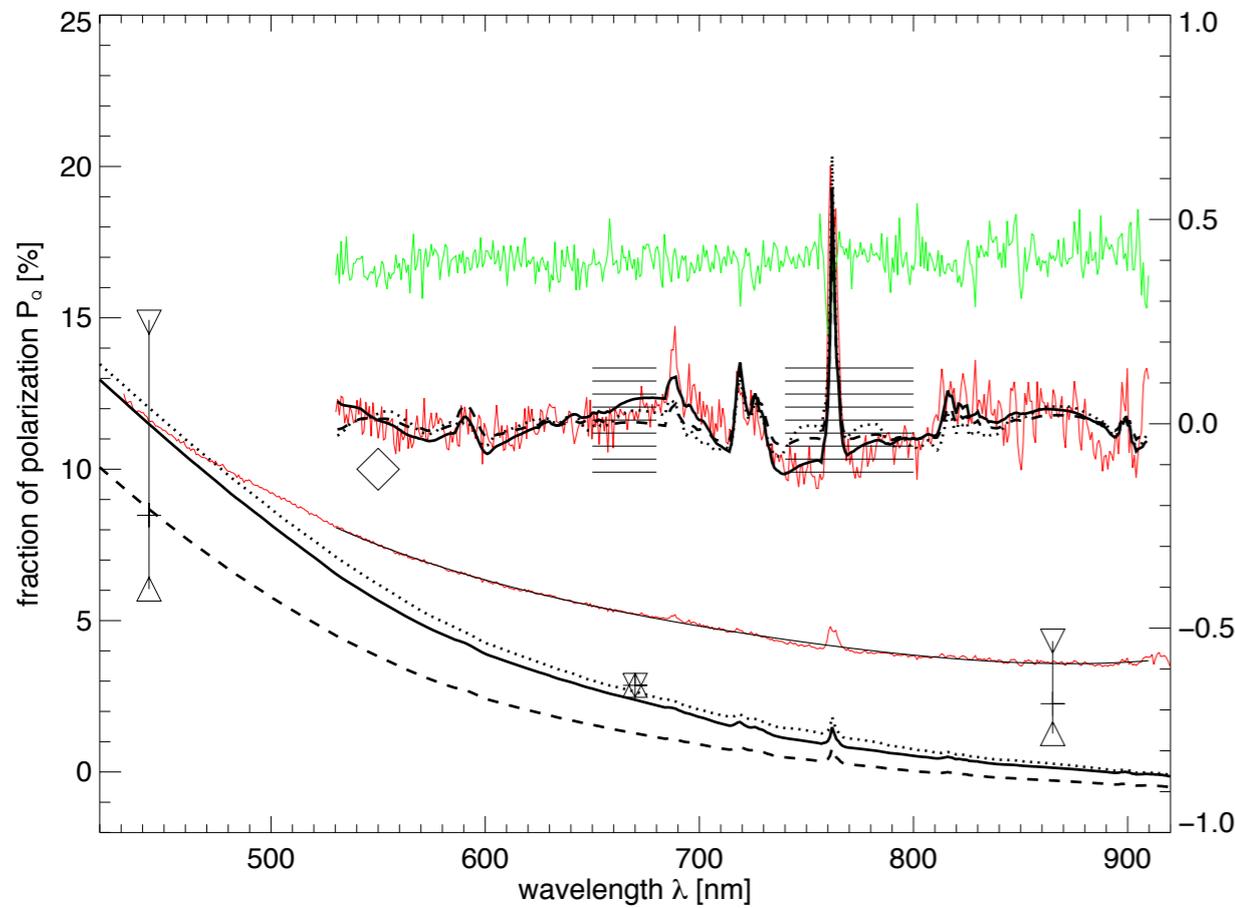
actual cloud cover: 42% ... 72%  
BSG model w/  $A=0.15$  58%

actual cloud cover: 27% ... 50%  
BSG model w/  $A=0.15$  38%

# Impact on Earthshine SP

25-Apr-2011:UT09

10-Jun-2011:UT01



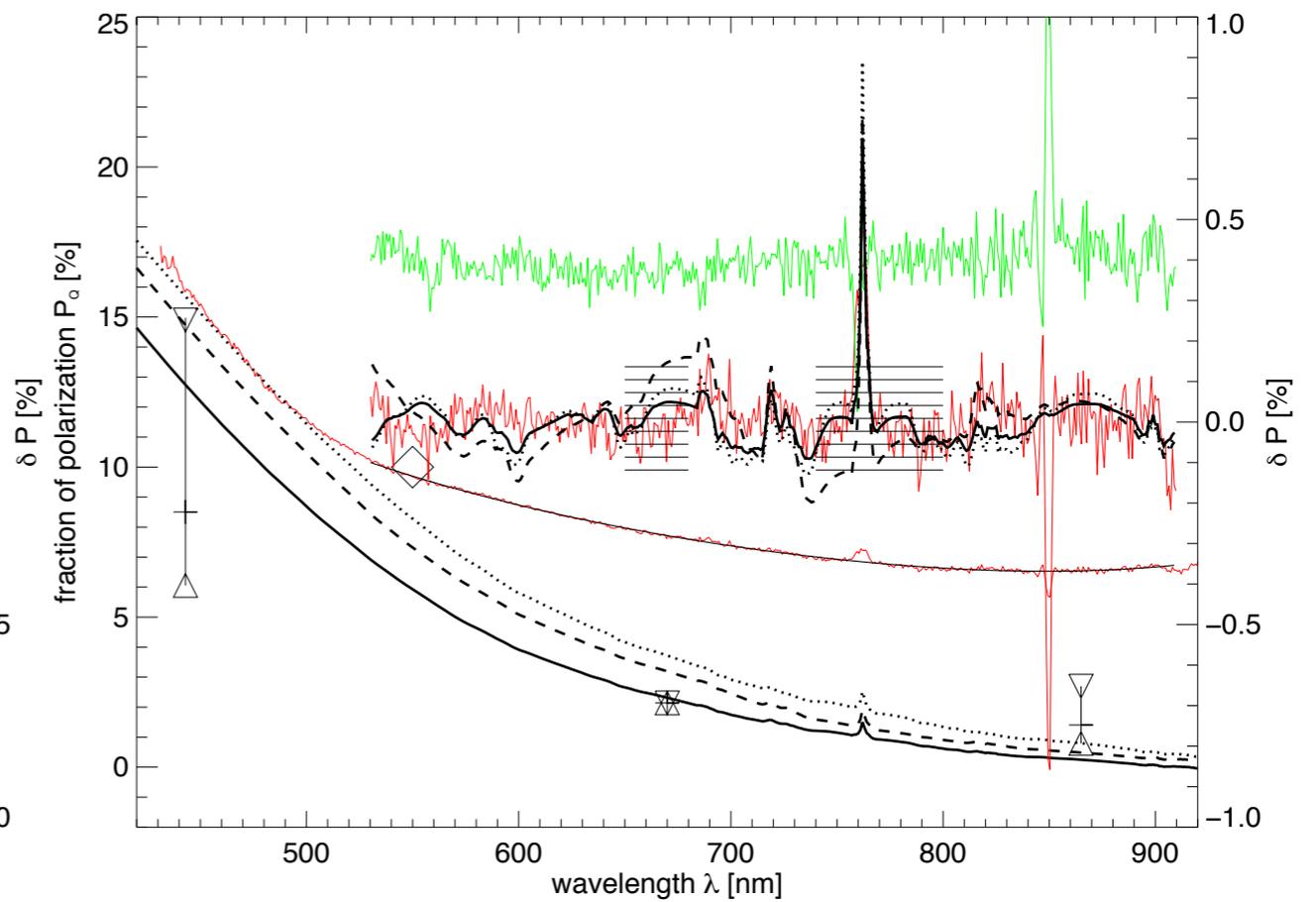
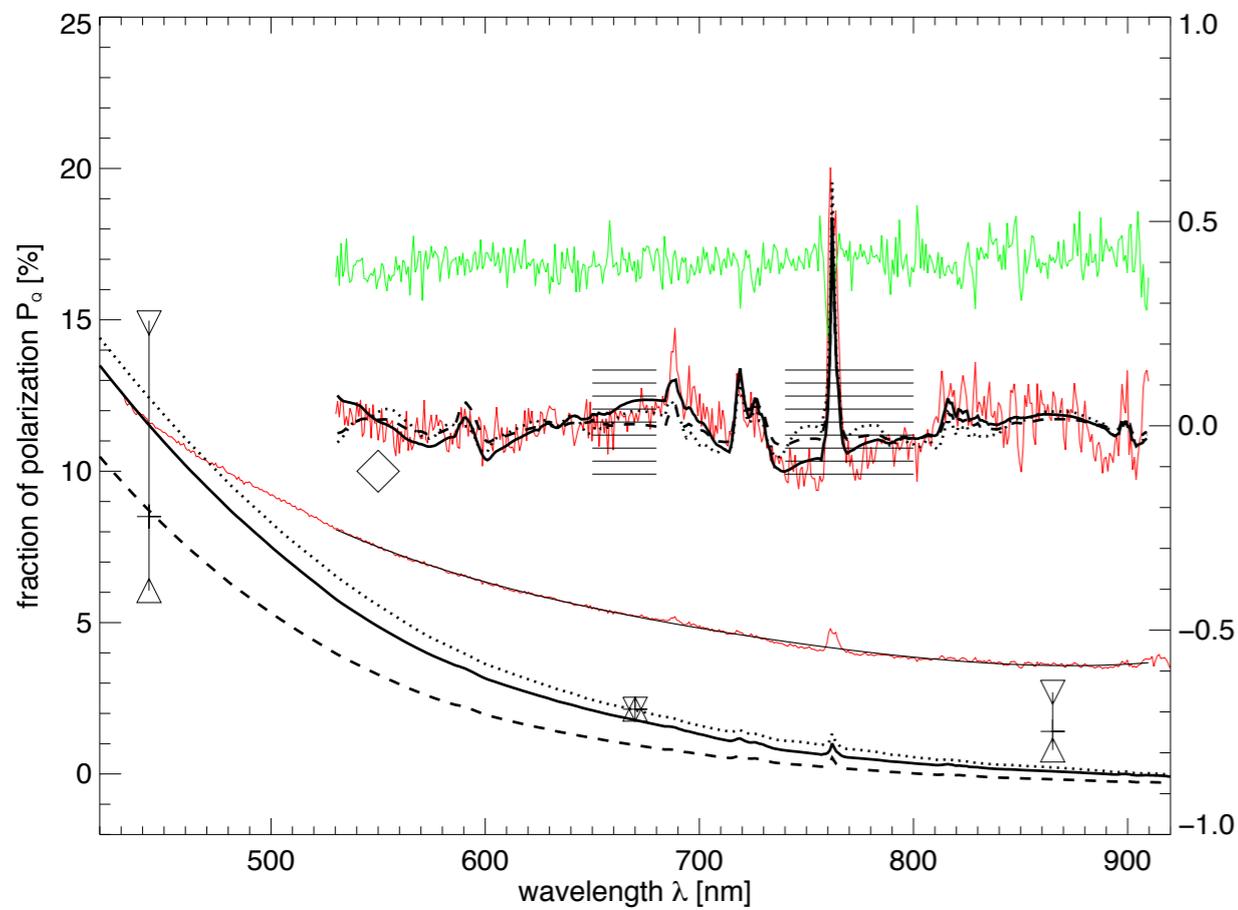
actual cloud cover: 42% ... 72%  
BSG model w/  $A=0.2$  46%

actual cloud cover: 27% ... 50%  
BSG model w/  $A=0.2$  28%

# Impact on Earthshine SP

25-Apr-2011:UT09

10-Jun-2011:UT01



actual cloud cover: 42% ... 72%  
"std" model: 44%

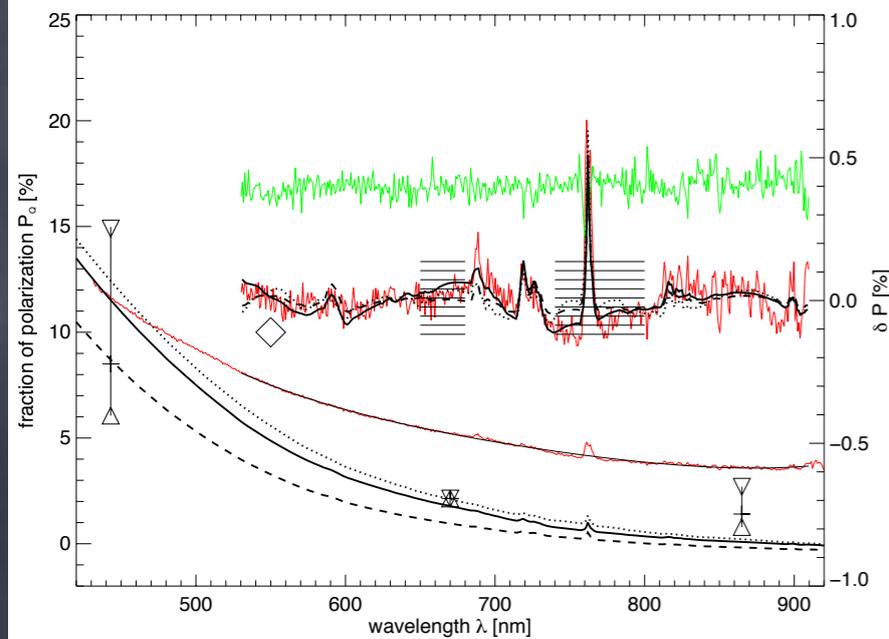
actual cloud cover: 27% ... 50%  
"std" model: 27%

# Lunar Depolarisation...

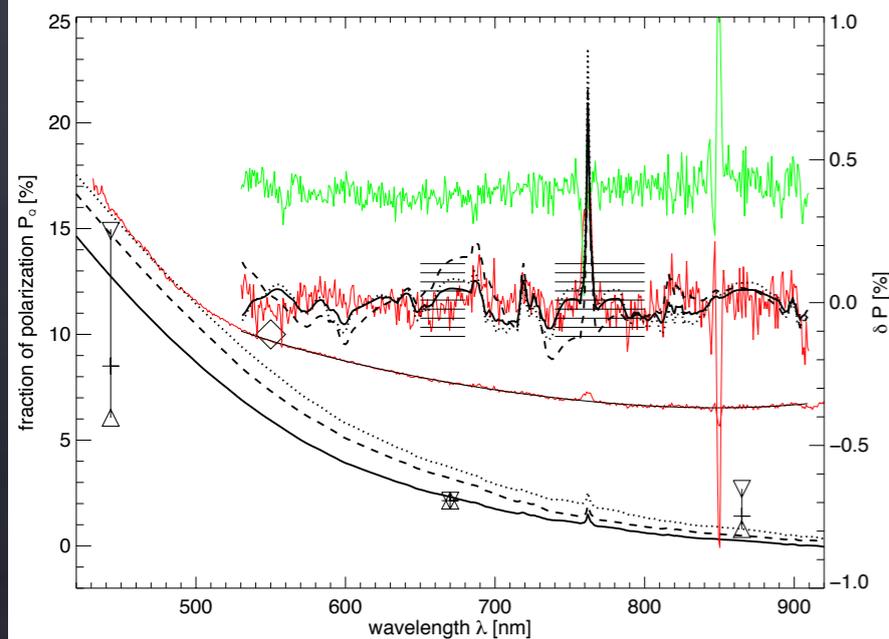
- wavelength (and albedo) dependence is poorly understood
- $\Delta$  Albedo of 0.1 could explain about 25% differences in the Earth's cloud coverage
- but it is unlikely that E and W lunar limbs have that large differences.
- can NOT explain the "red" continuum excess
- we would like to apply a "realistic" lunar depolarisation law... (KM??)

# (Spectro-)Polarimetry of ES

25-Apr-2011 1:UT09

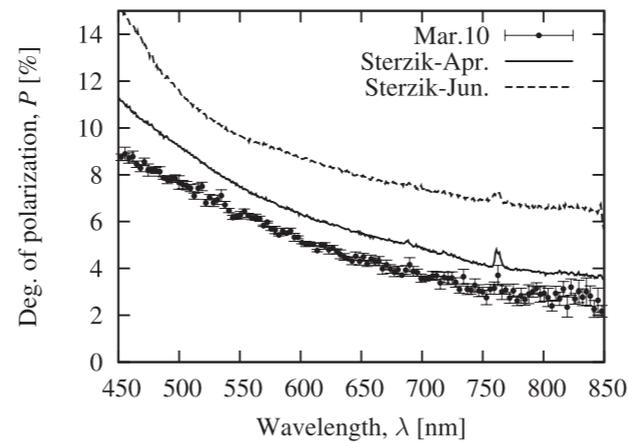


10-Jun-2011 1:UT01

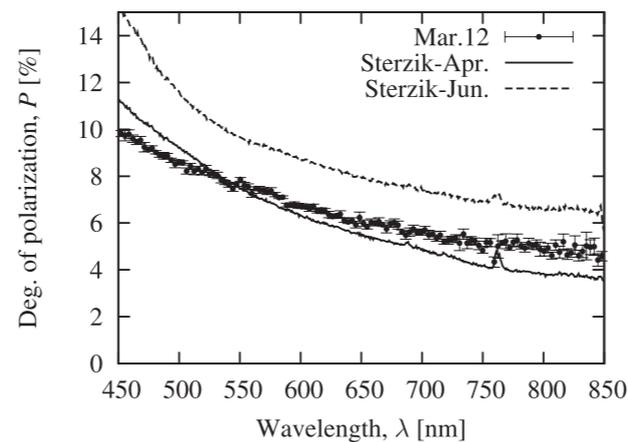


Sterzik, M. F., Bagnulo, S. & Pallé, E. **Biosignatures** as revealed by spectropolarimetry of Earthshine. *Nature* **483**, 64–66 (2012).

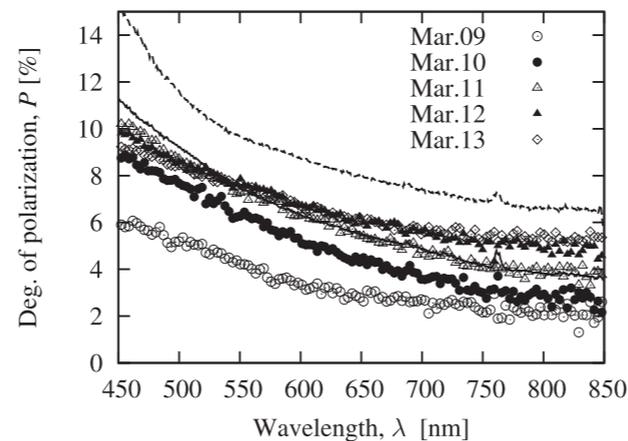
(b)



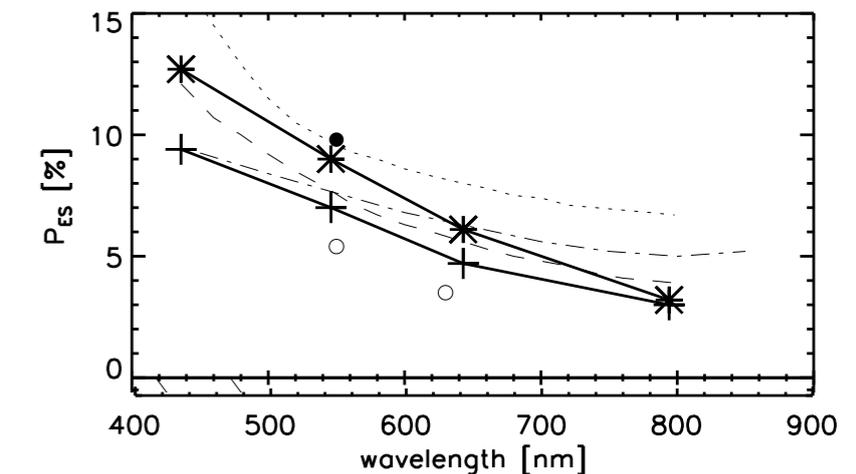
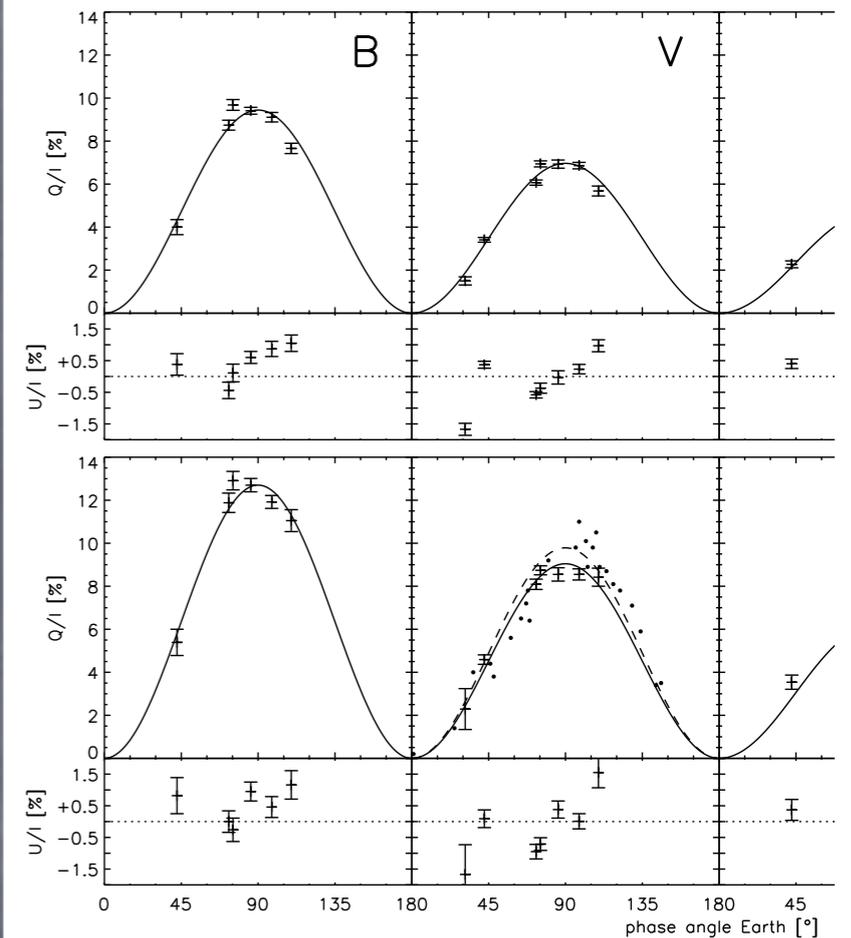
(d)



(f)



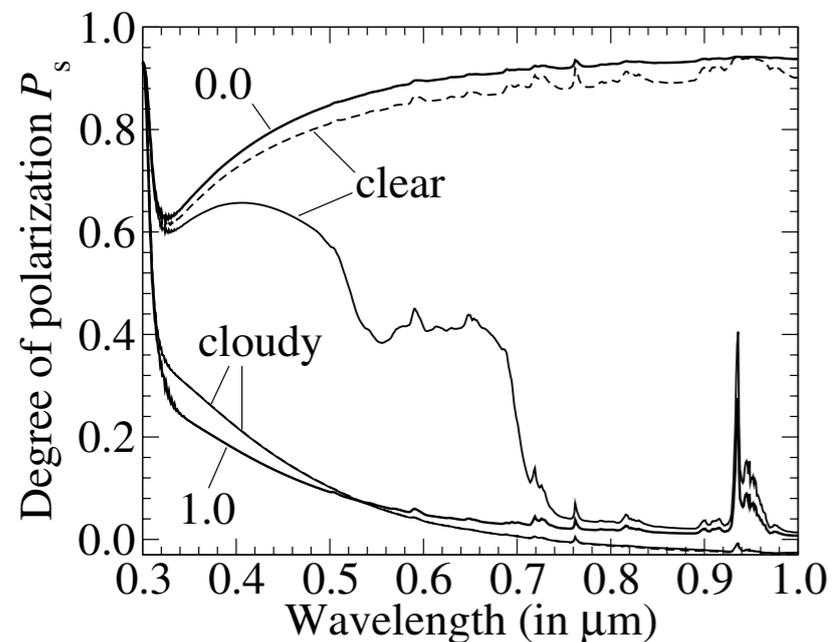
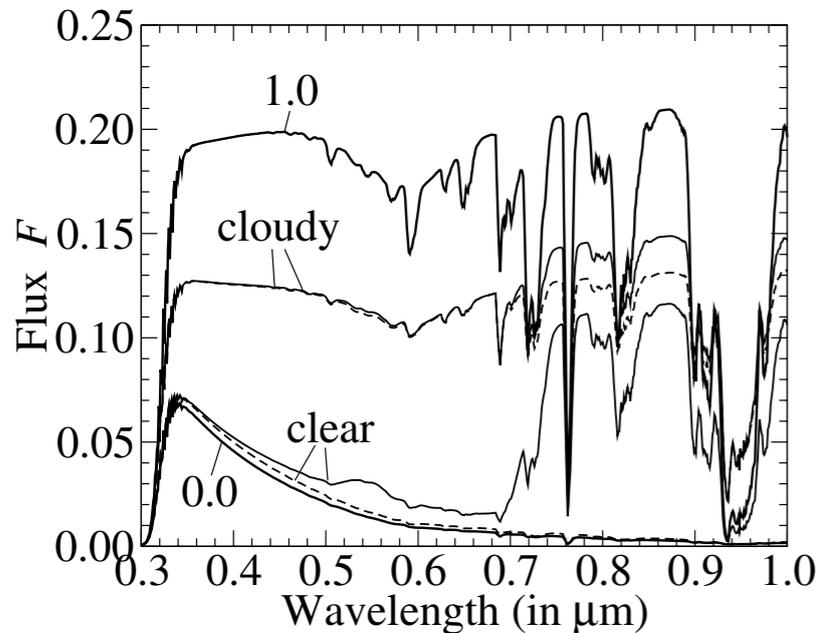
Takahashi, J. *et al.* **Phase Variation** of Earthshine Polarization Spectra. *Publications of the Astronomical Society of Japan* **65**, 38 (2013).



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).

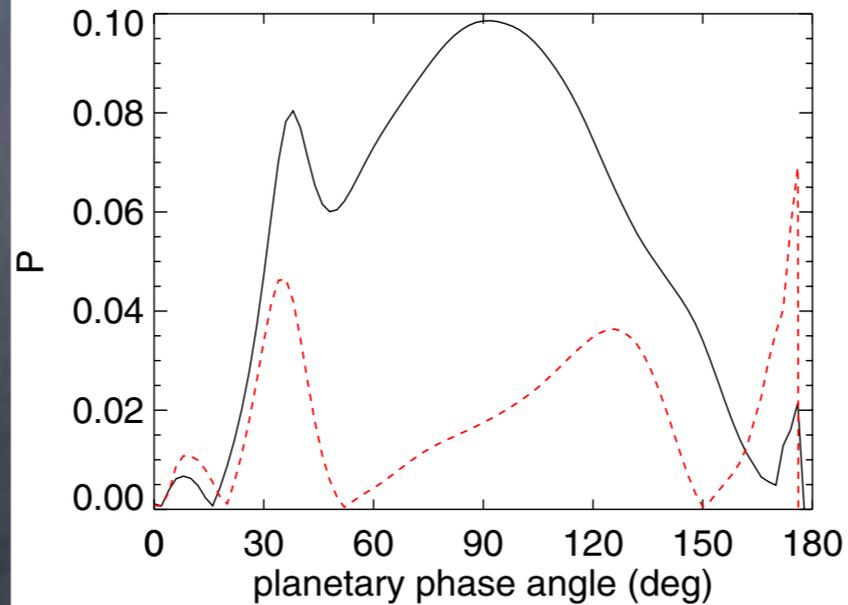
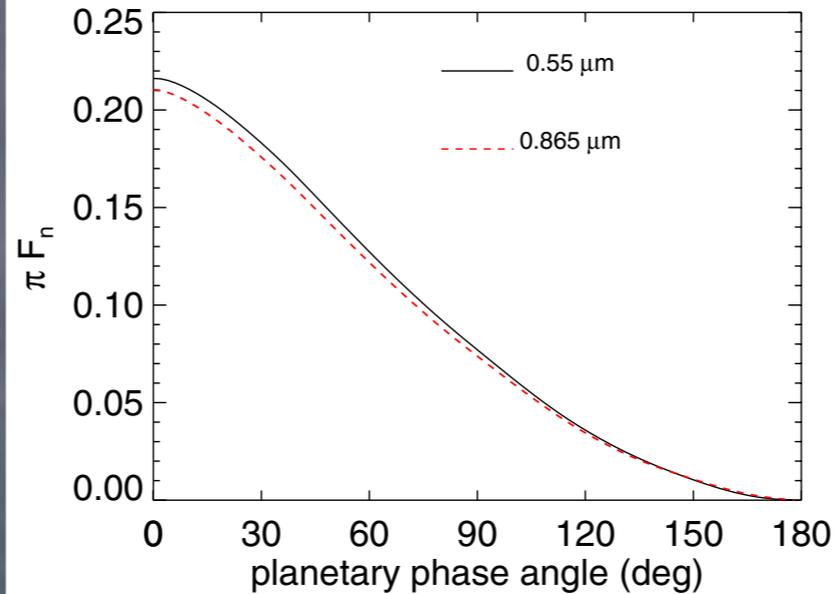
# towards 3D-vec. rad. transfer

## plane parallel



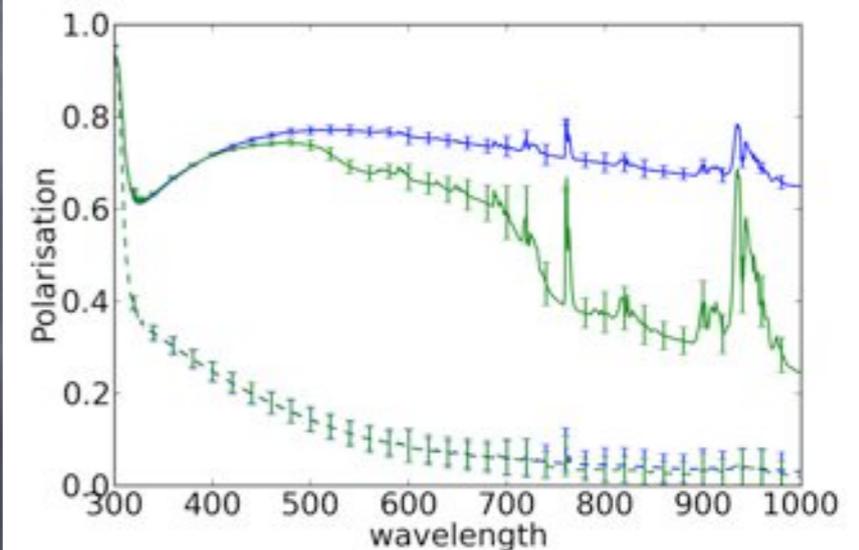
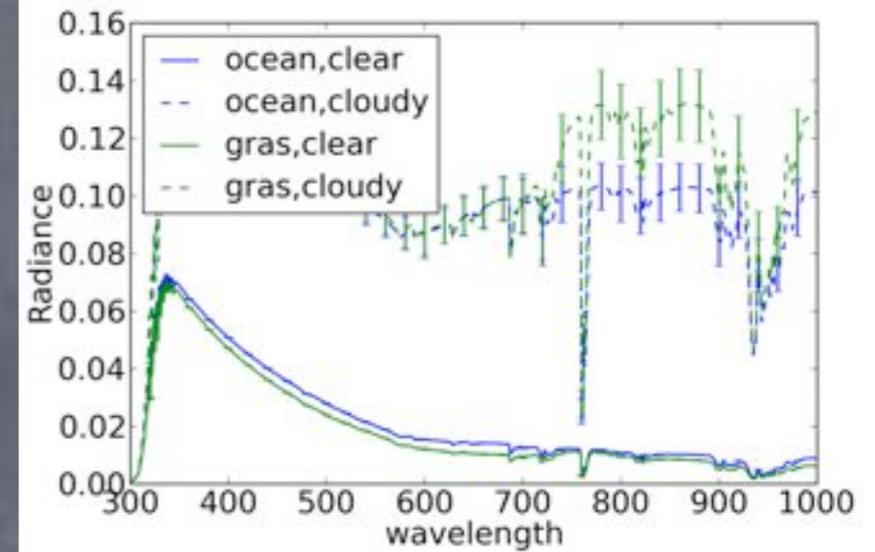
Stam, D. M. Spectropolarimetric signatures of Earth-like extrasolar planets. *A&A* **482**, 989–1007 (2008).

## cloud/water prop.



Karalidi, T., Stam, D. M. & Hovenier, J. W. Looking for the **rainbow** on exoplanets covered by liquid and icy water clouds. *A&A* **548**, A90 (2012).

## 3D MYSTIC



Emde, C., Buras, R. & Mayer, B. ALIS: 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).

# SP of ES

- (+) robust tool to retrieve integrated surface and atmospheric properties
- (+) sensitive on biosignatures (VRE, O<sub>2</sub>, H<sub>2</sub>O)
- (-) restricted phase coverage
- (-) improve lunar depolarisation models
- (-) improve Earth VRT atmosphere/surface/haze modeling