

Polarimetry of Earthshine as a Test of Ocean Detection on Exoplanets

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We present our ongoing work on polarimetry of Earthshine on the Moon. Theoretical models estimate that specular reflection on smooth liquid surface on a planet will cause a great polarized fraction in the reflected light from the planet. To confirm this, we have been conducting polarimetry of Earthshine on the waxing and the waning Moon. 6-night data have been obtained up to present. In the preliminary analysis, apparent difference has not been detected between Earthshine on the waxing and the waning Moon.

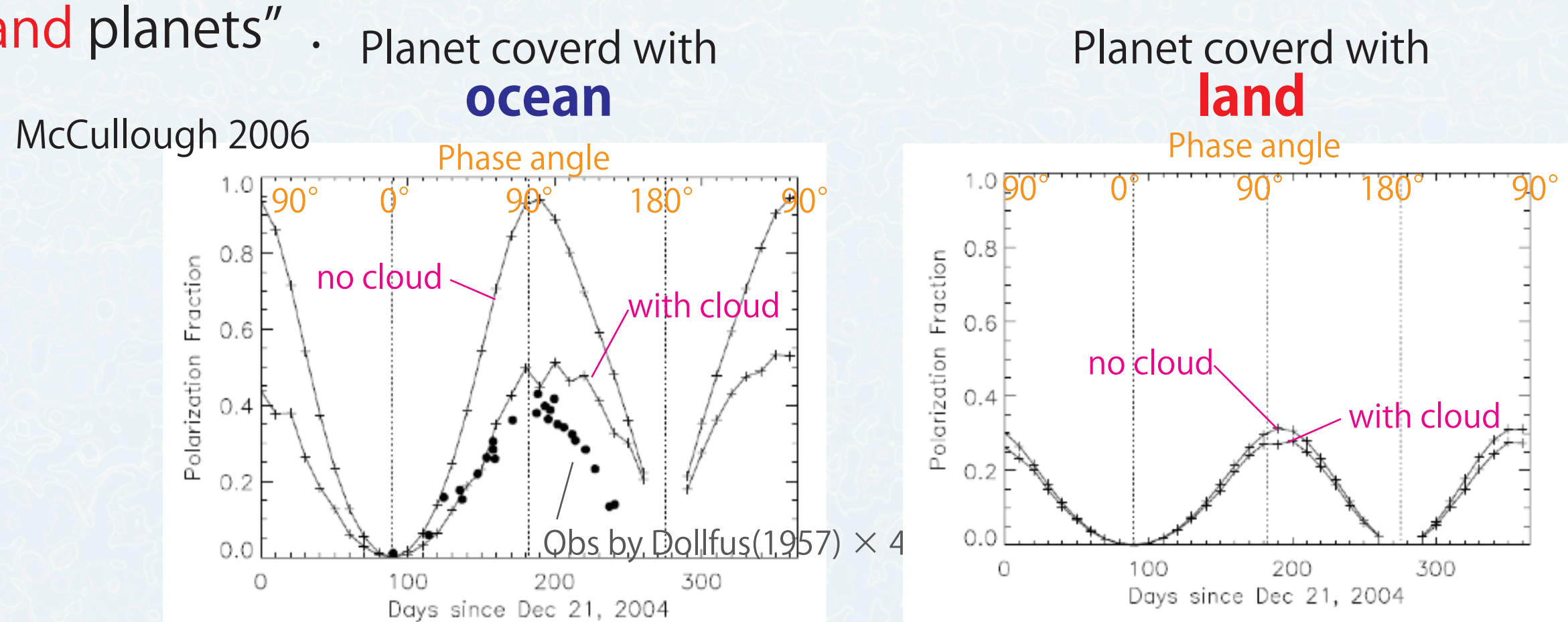
1. Introduction

(1) Motivation

- * Existence of liquid on a planet is one of keys for its habitability.
- * How can we discover a planet with an ocean?

(2) Polarization models of exoplanets

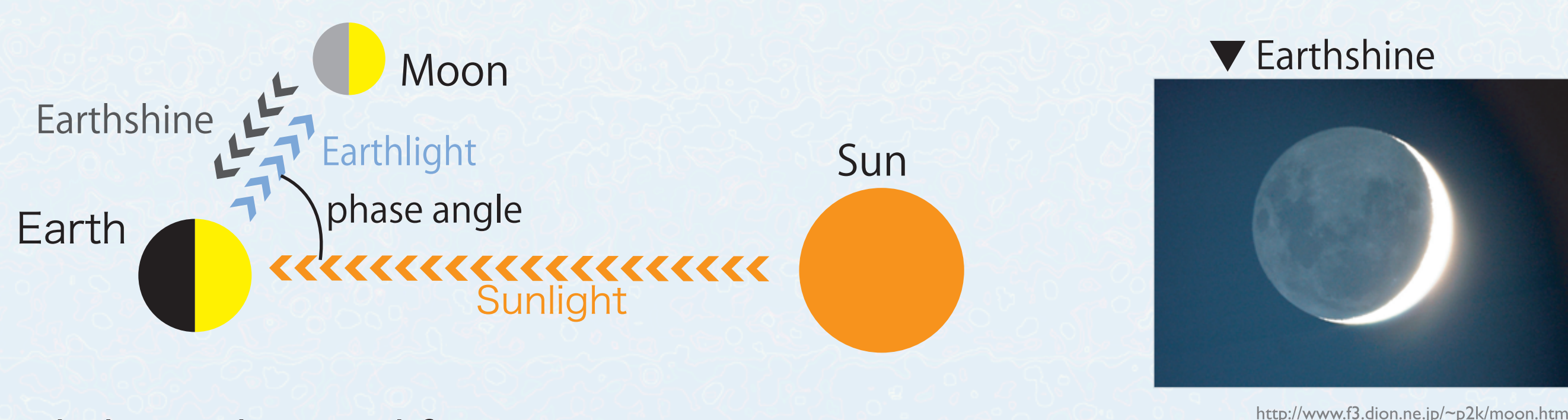
- * Specular reflection on smooth liquid surface on a planet will cause a great polarized fraction in the total reflected light (McCullough 2006, Zuger+2010) => Difference in polarization fraction between "ocean planets" and "land planets"



Polarimetry of extrasolar planets is a possible method to find a planet with an ocean. => It is necessary to confirm the model by observations.

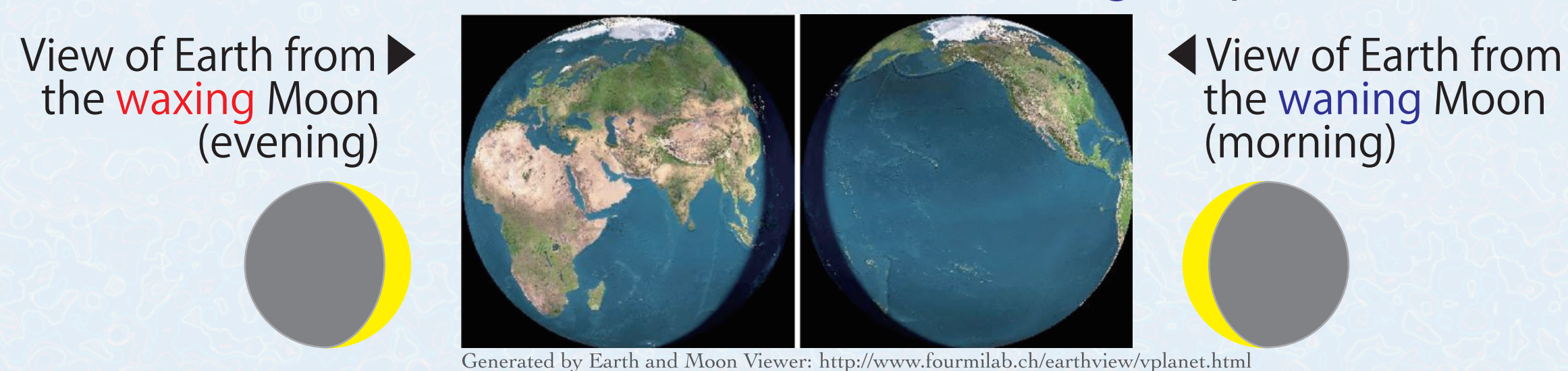
(3) Earthshine for the test

- * The only planet known to have ocean is the Earth.
- * Earthshine: the Moon's night side illuminated by the Earthlight.



- * Earthshine observed from Japan:

- Waxing Moon = from a land-dominant surface = lower polari estimated
- Waning Moon = from an ocean-dominant surface = higher polari estimated



2. Observations

Type: Imaging polarimetry (Hyogo, Japan)

Telescope: 60cm reflector (F12) at Nishi-Harima Astronomical Observatory

Instrument: Simultaneous Imaging/Spectroscopic Polarimeter

(Nishida, Kobe-U Master thesis, 2008)

This instrument obtains $F_0, F_{45}, F_{90}, F_{135}$ simultaneously and guarantees strict simultaneity of telluric conditions (F_θ : Flux at an oscillation angle θ [deg]).

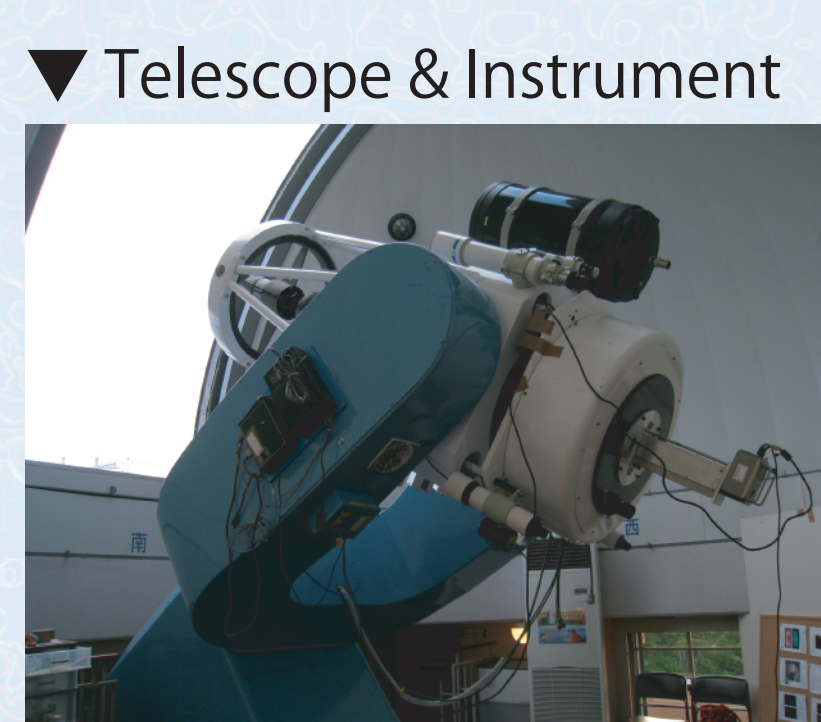
Wavelength: V band (551 nm)

Field of view (FOV): $\sim 2.2' \times 8.7'$

Exposure time: 10 - 60 sec

Date: From May, 2010 (ongoing)

- * 6-night data have been obtained (4 for the waxing Moon, 2 for the waning Moon).



3. Data reduction

- (1) Dark subtraction, flat fielding

$$\frac{Q}{I} = \frac{F_0 - F_{90}}{F_0 + F_{90}} \quad (a)$$

- (2) Divide an image into $F_0, F_{45}, F_{90}, F_{135}$ images.

- (3) Make $F_0 + F_{0+90}$ and $F_0 - F_{0+90}$ images ($\theta=0, 45$).

$$\frac{U}{I} = \frac{F_{135} - F_{45}}{F_{135} + F_{45}} \quad (b)$$

- (4) Sky subtraction

F_θ : Flux at an oscillation angle θ [deg]

- (5) Make Q/I and U/I images (eq. a & b).

- (6) Correction of instrumental polarization

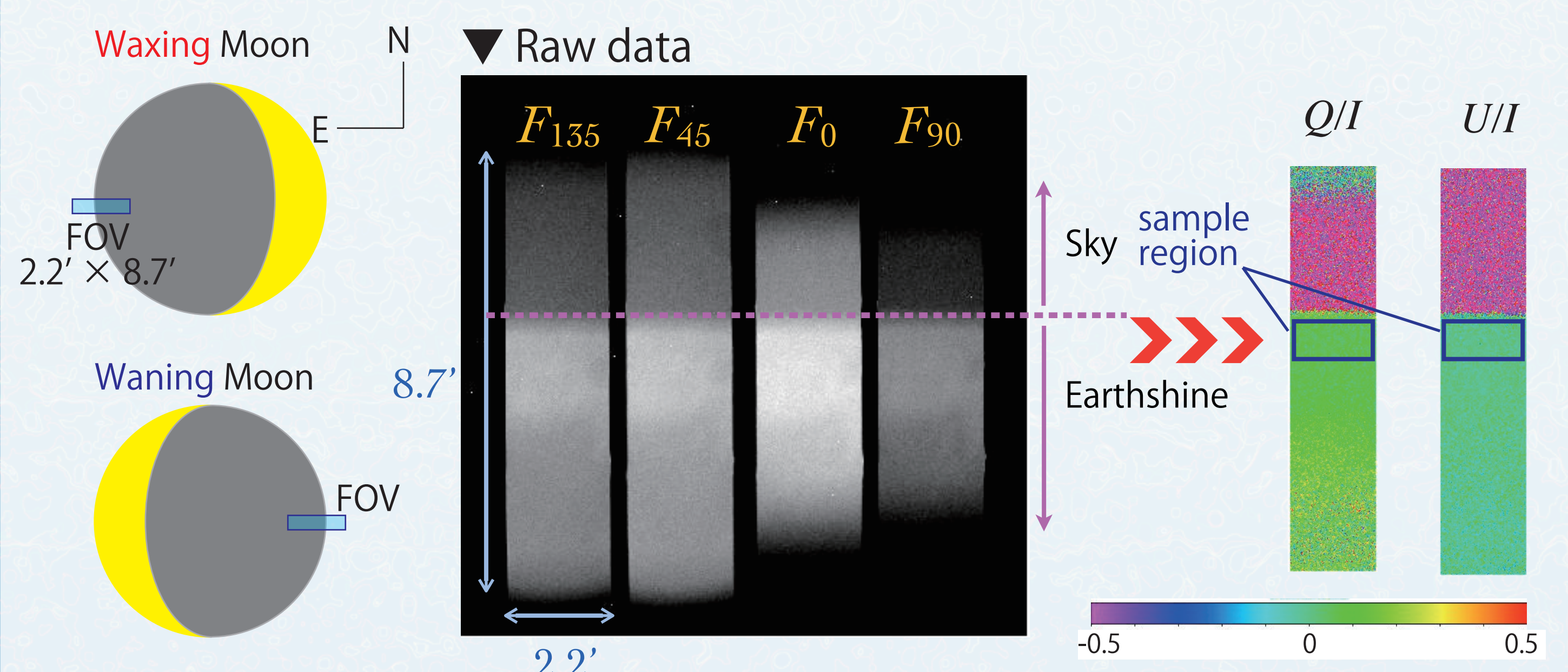
$$P = \sqrt{\left(\frac{Q}{I}\right)^2 + \left(\frac{U}{I}\right)^2} \quad (c)$$

(using polarized and unpolarized standard stars)

- (7) Derive the representative value of the sample region

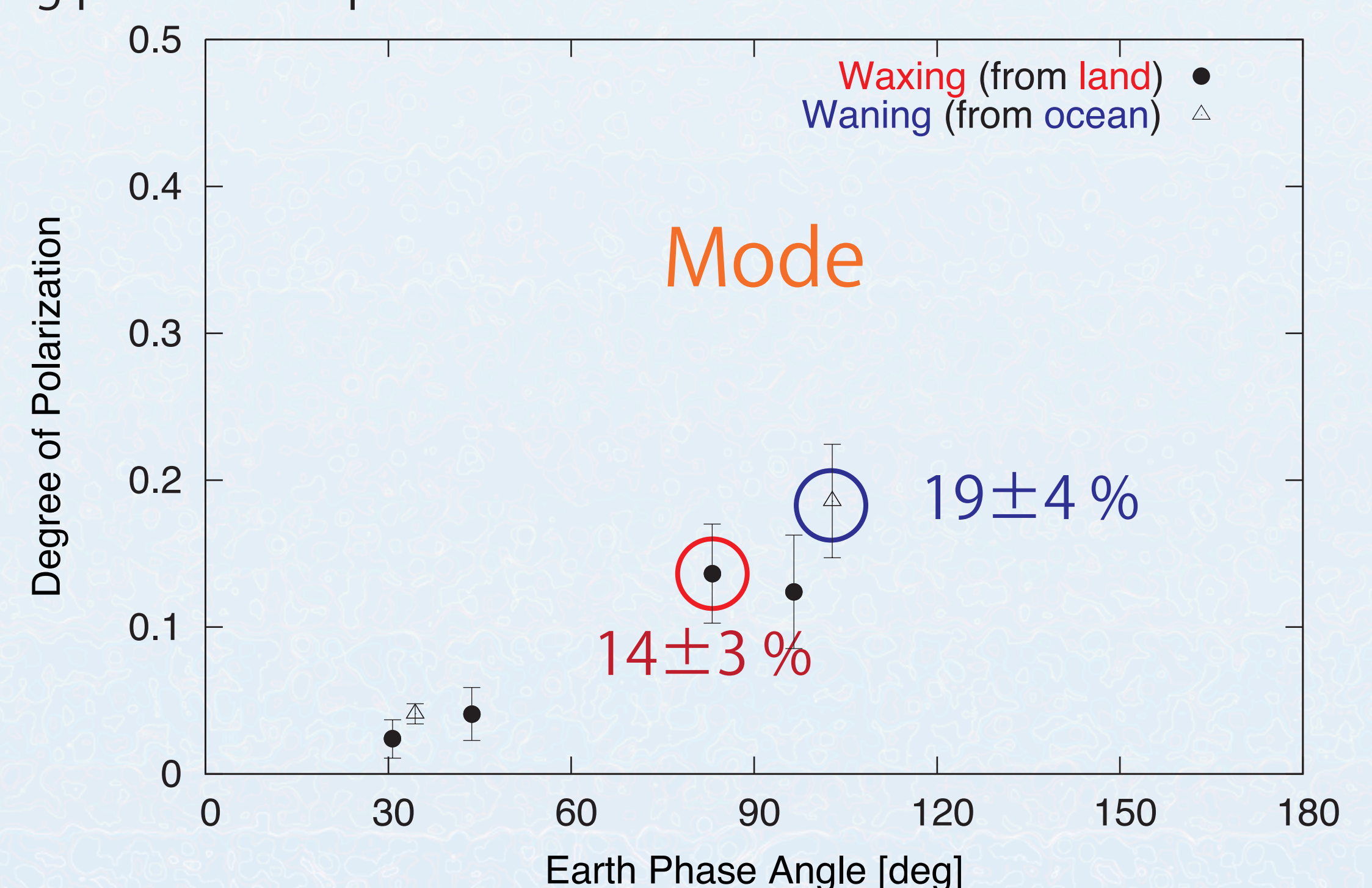
- (8) Derive the degree of polarization P (eq. c).

- (9) Derive the mean value of P for the night. ※ IRAF is used for the reduction.

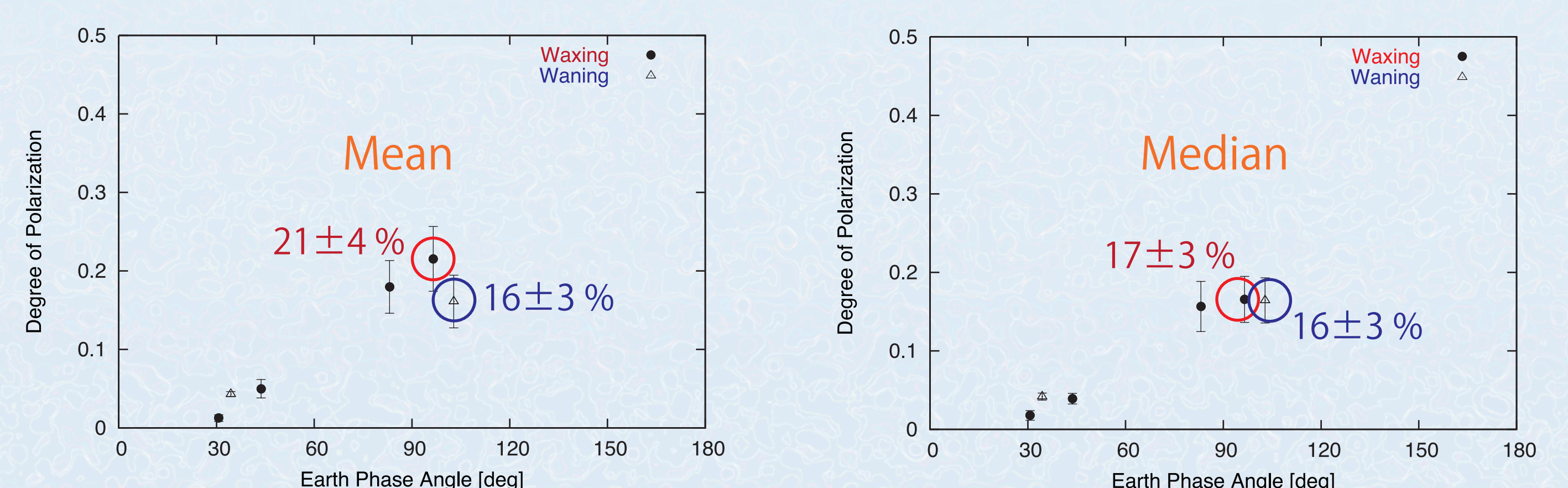


4. Results

When **mode** is applied to the representative value in 3-(7), we have the following polarization phase curve:



Earthshine on the **waning** Moon (from **ocean**) appears to be more **highly** polarized than that on the **waxing** Moon (from **land**), as estimated. However, when **mean** or **median** is applied, we have different results:



We need to resolve the discrepancy to reach final conclusions. Further observations are scheduled after modification of the instrument.