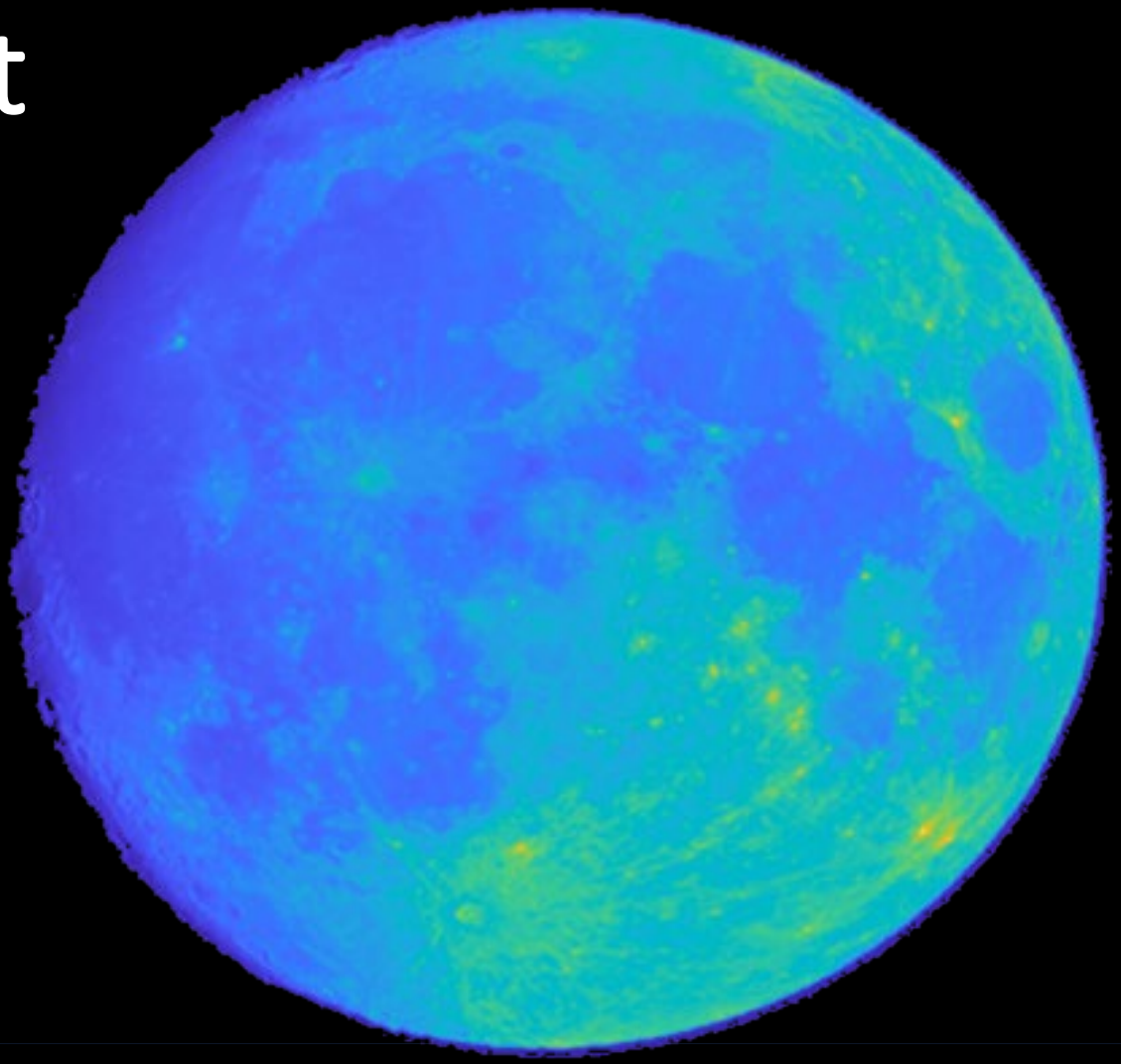
Disk-averaged and disk-resolved polarization of moonlight across lunar phases



CalCon - 12 June 2023

Montana State University

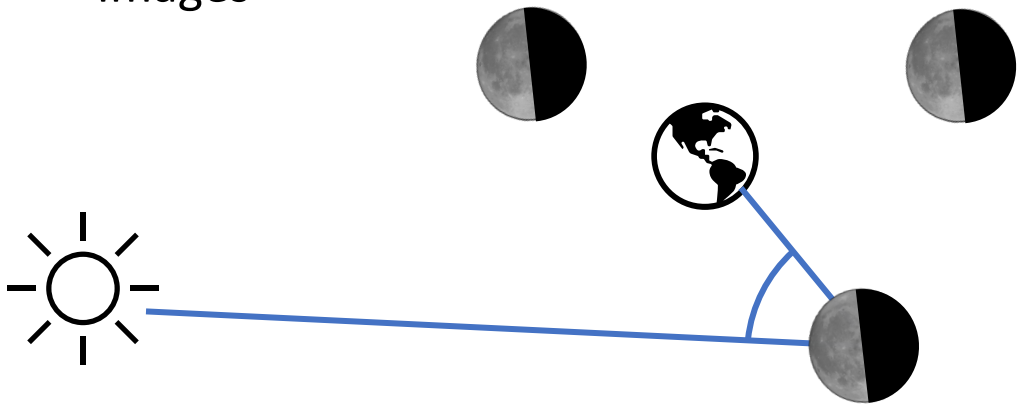
Erica Venkatesulu, Sierra Dabby, and Joseph A. Shaw

Moonlight polarization motivation

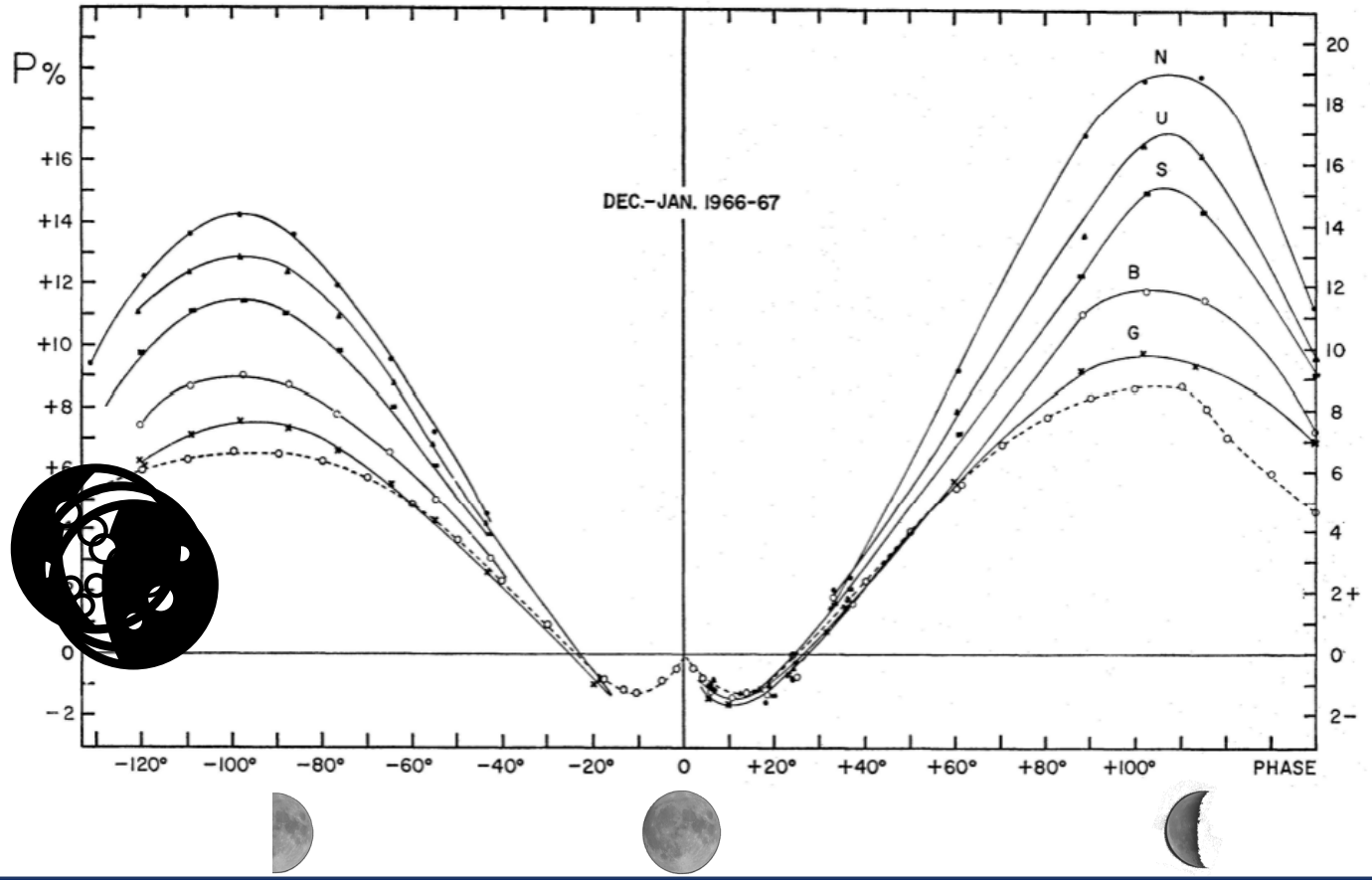
- Nighttime remote sensing
  - Source of visible and SWIR radiance
- Moon as a radiometric calibration target
  - Problem for radiometric instruments with polarization sensitivity

Moonlight polarization background

- Phase angle
- Disk-averaged measurements
- Disk-resolved measurements
  - Point measurements/scans with spatial resolution
  - Images



Bands from 320-600 nm
Coyne and Pellicori, 1970



Division-of-focal-plane polarization imagers

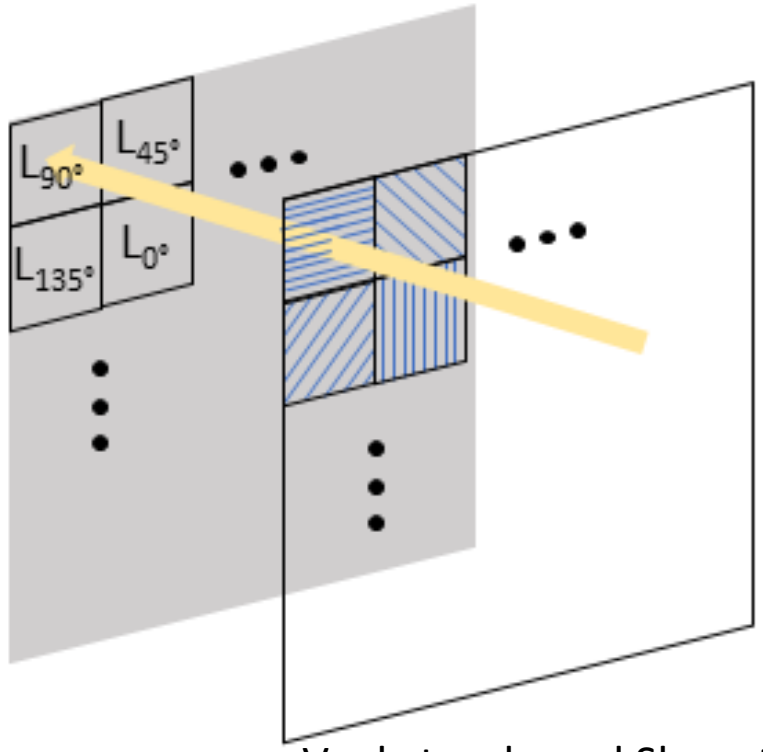
- Monochrome camera
- Contrast ratio of ≥ 100
  - Transmitted power / extinguished power
- Linear Stokes vector

$$S_0 = I = \frac{1}{2}(L_{0^\circ} + L_{45^\circ} + L_{90^\circ} + L_{135^\circ})$$

$$S_1 = Q = L_{0^\circ} - L_{90^\circ}$$

$$S_2 = U = L_{45^\circ} - L_{135^\circ}$$

$$DoLP = \frac{\sqrt{S_1^2 + S_2^2}}{S_0} \qquad AoP = \frac{1}{2}\arctan\frac{S_2}{S_1}$$

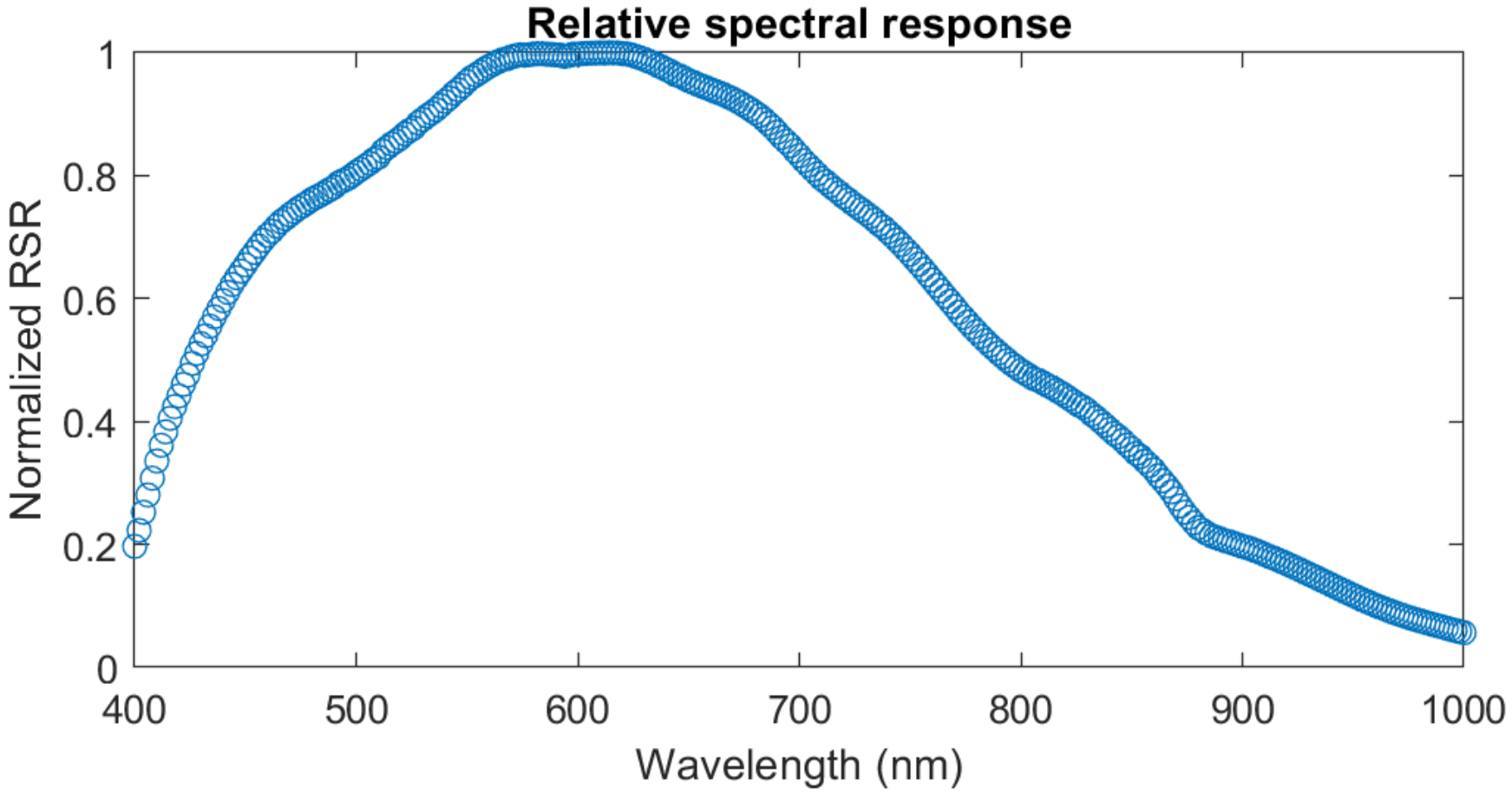


Venkatesulu and Shaw, 2022

Imaging systems

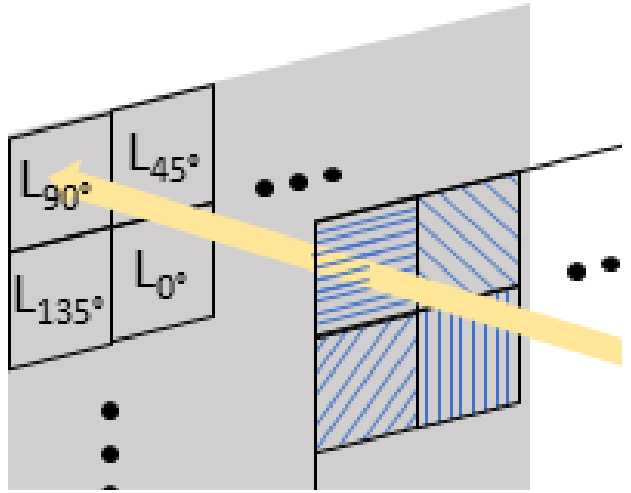
- Telescope
  - 2-m focal length, f/10
  - Moon ~ 2700 pixels
- Telephoto lens
  - 300-mm focal length, f/11
  - Moon ~ 400 pixels

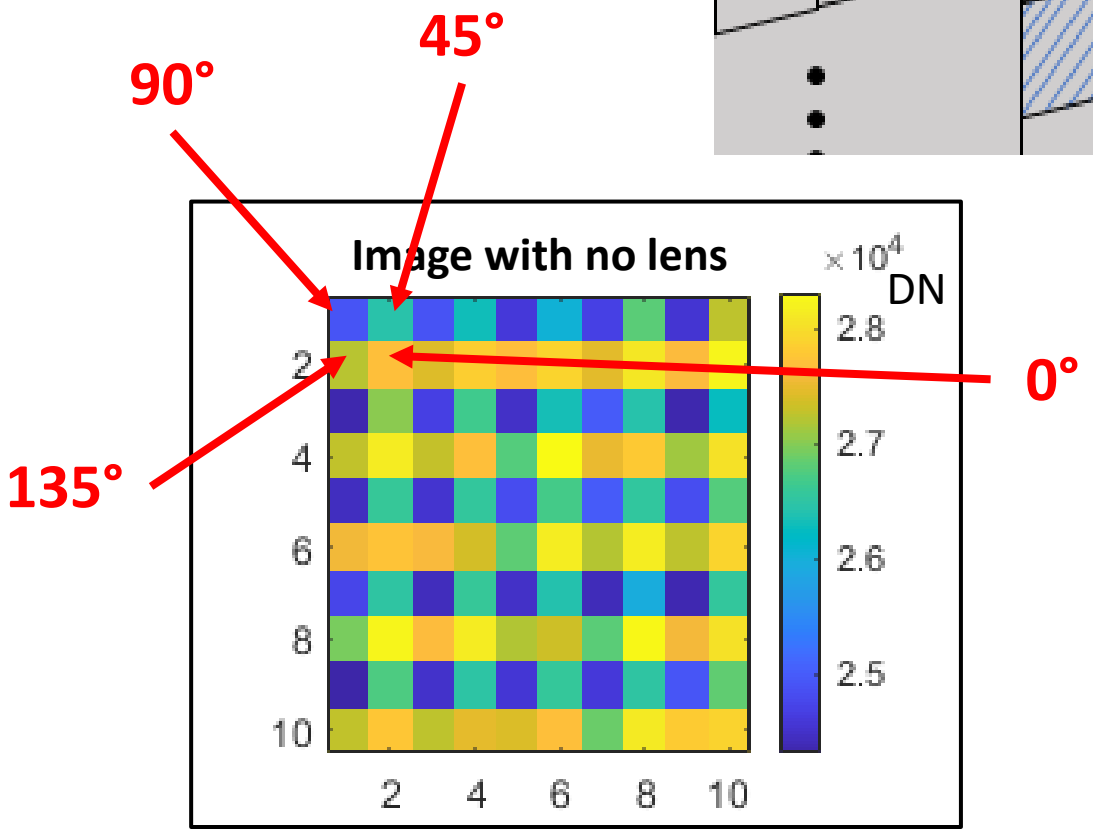
Spectral characterization



Polarimetric calibration

1. Polarimetric aberrations in lens
2. Different transmissions for differently oriented nanowires

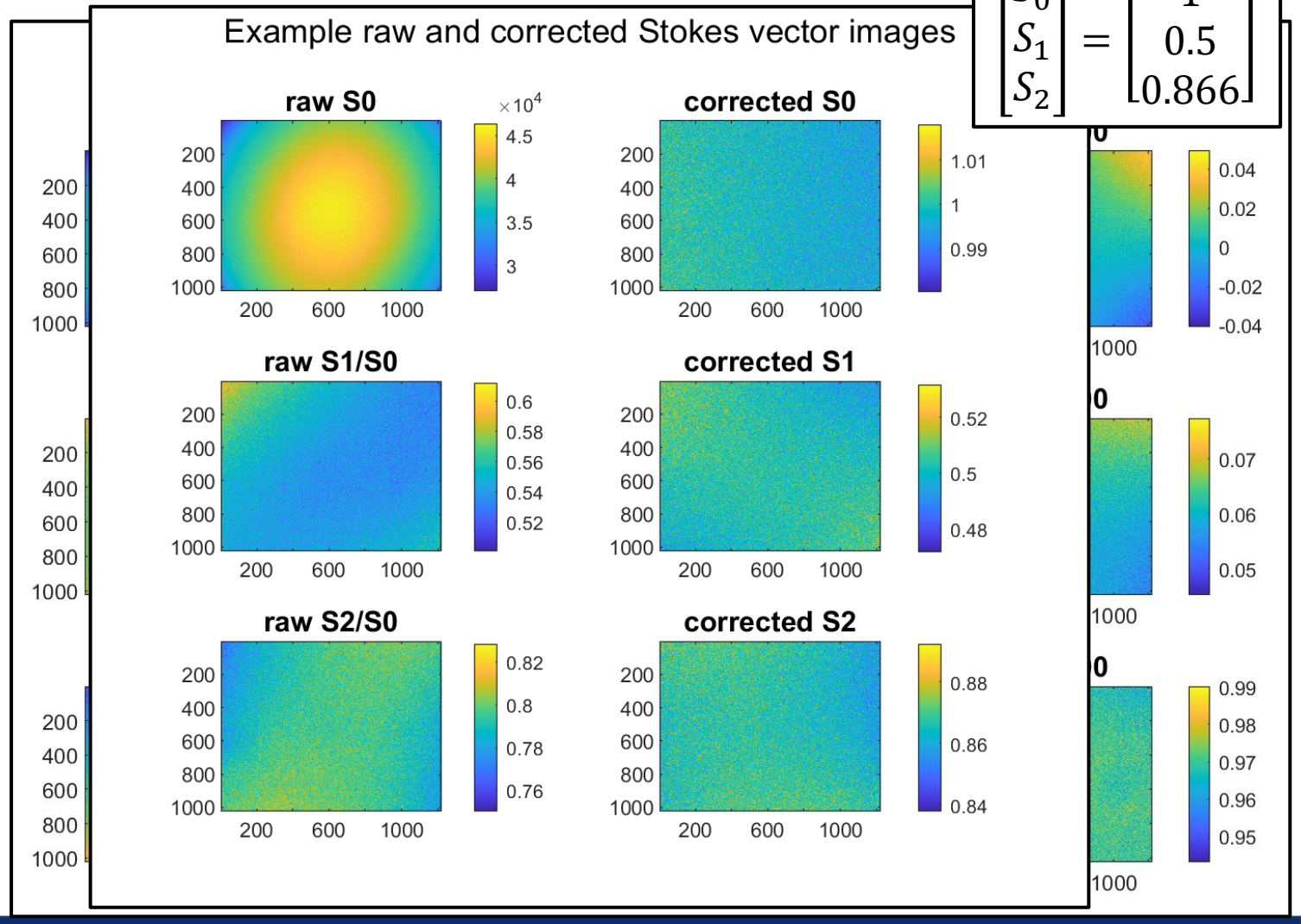




Polarimetric calibration

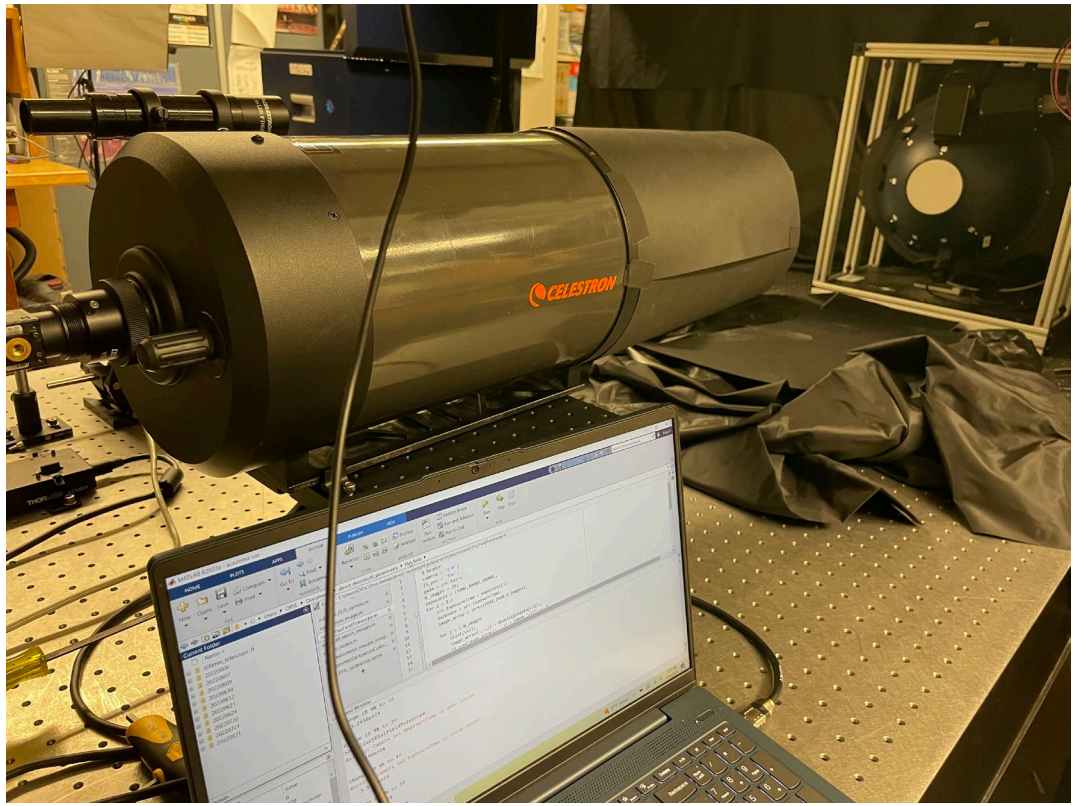
$$\begin{bmatrix} S_0 \\ S_1 \\ S_2 \end{bmatrix} = \begin{bmatrix} 1 \\ 0.5 \\ 0.866 \end{bmatrix}$$

- Mueller matrix for 300-mm lens
- Spatial standard deviations
  - S0 image: 0.0649 to 0.0038
  - S1 image: 0.0114 to 0.0058
  - S2 image: 0.0080 to 0.0057



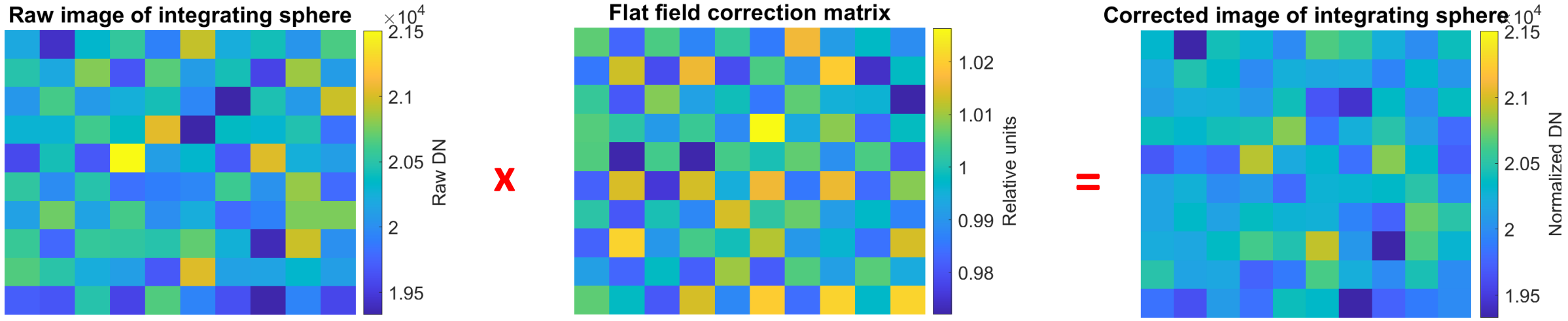
Telescope system polarization correction

- No large aperture integrating sphere or polarizer
- Schmidt-Cassegrain telescope: small polarimetric aberrations
- Transmission of nano-wire polarizers depends on angle of illumination
- Out of focus image vs in focus image: similar angular range of illumination



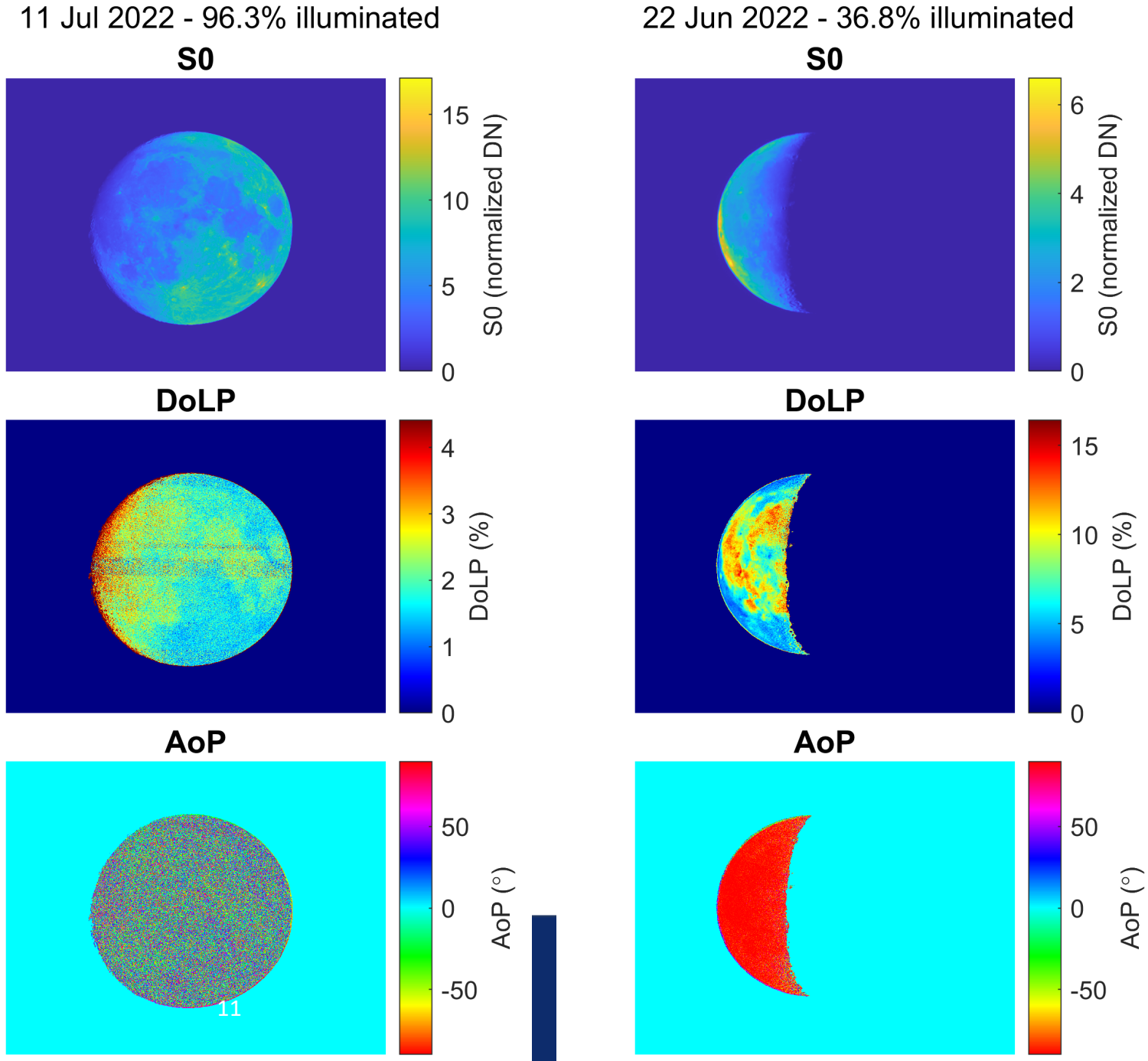
Flat field

- Measure difference in transmission with out of focus images of integrating sphere
- Spatial SD decreased by 23%



Telescope images

- Full moon less polarized than crescent moon
- AoP ⊥ plane of vision
- Umov effect
  - Darker surfaces are more polarized



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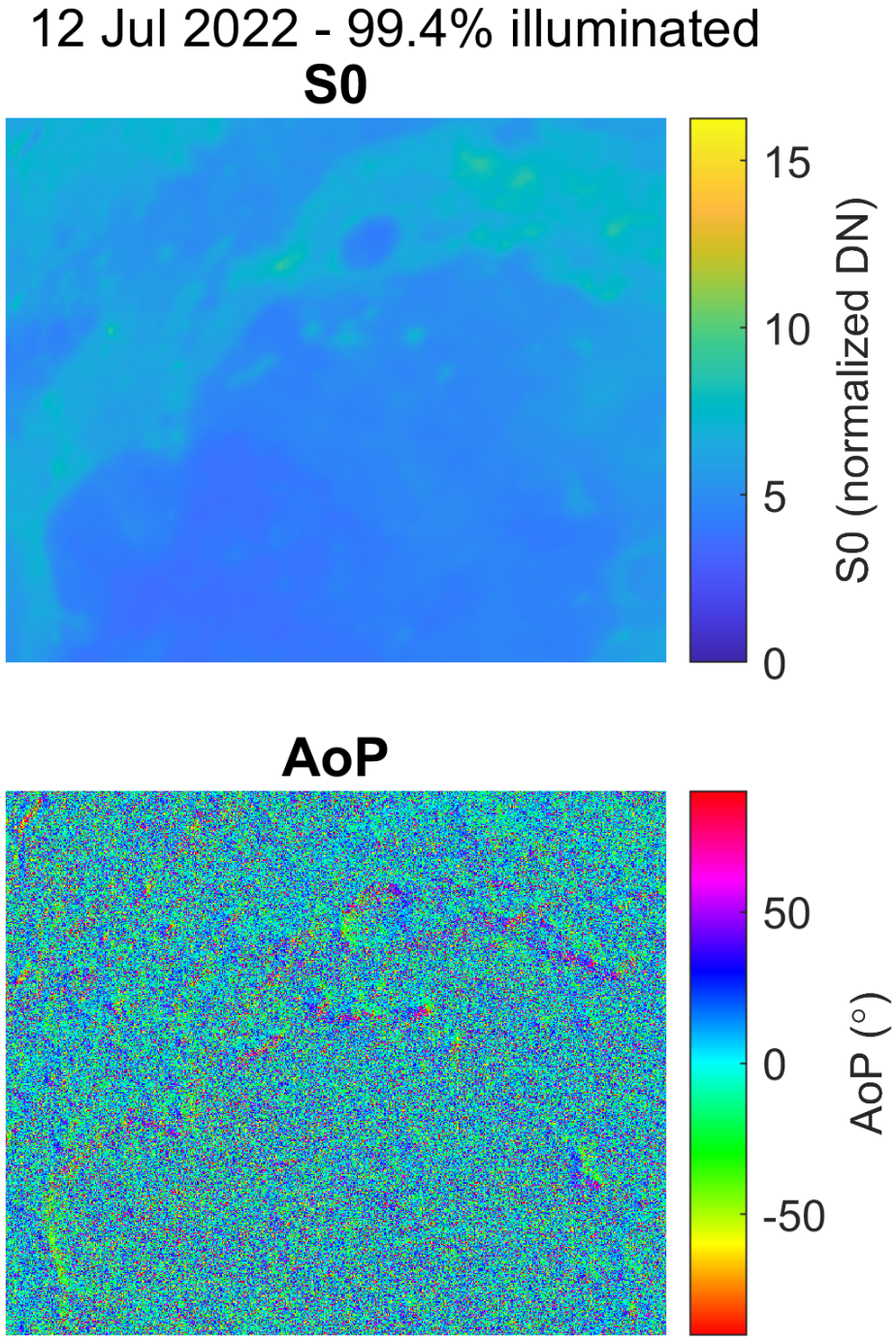
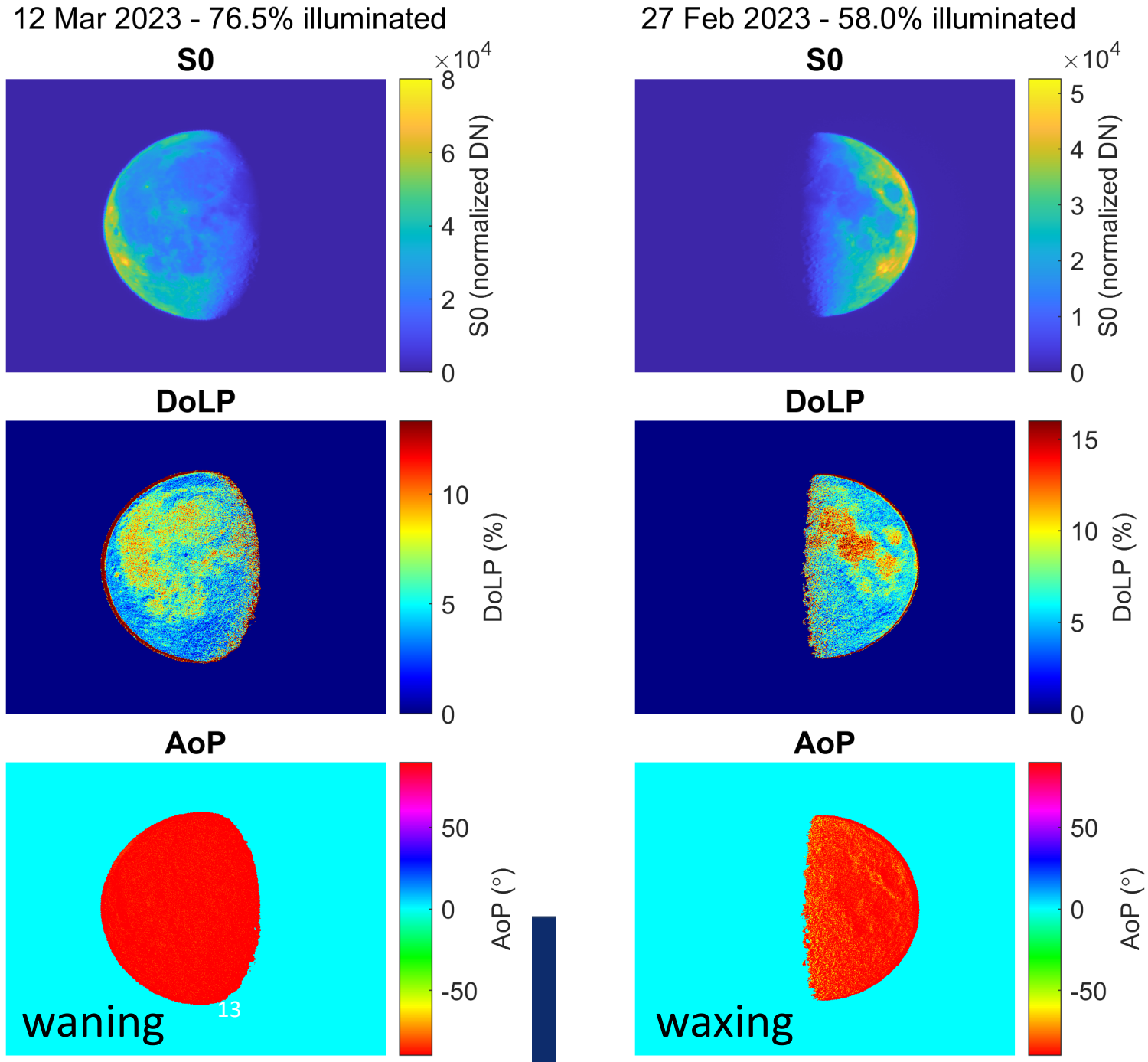
Telescope image of AoP

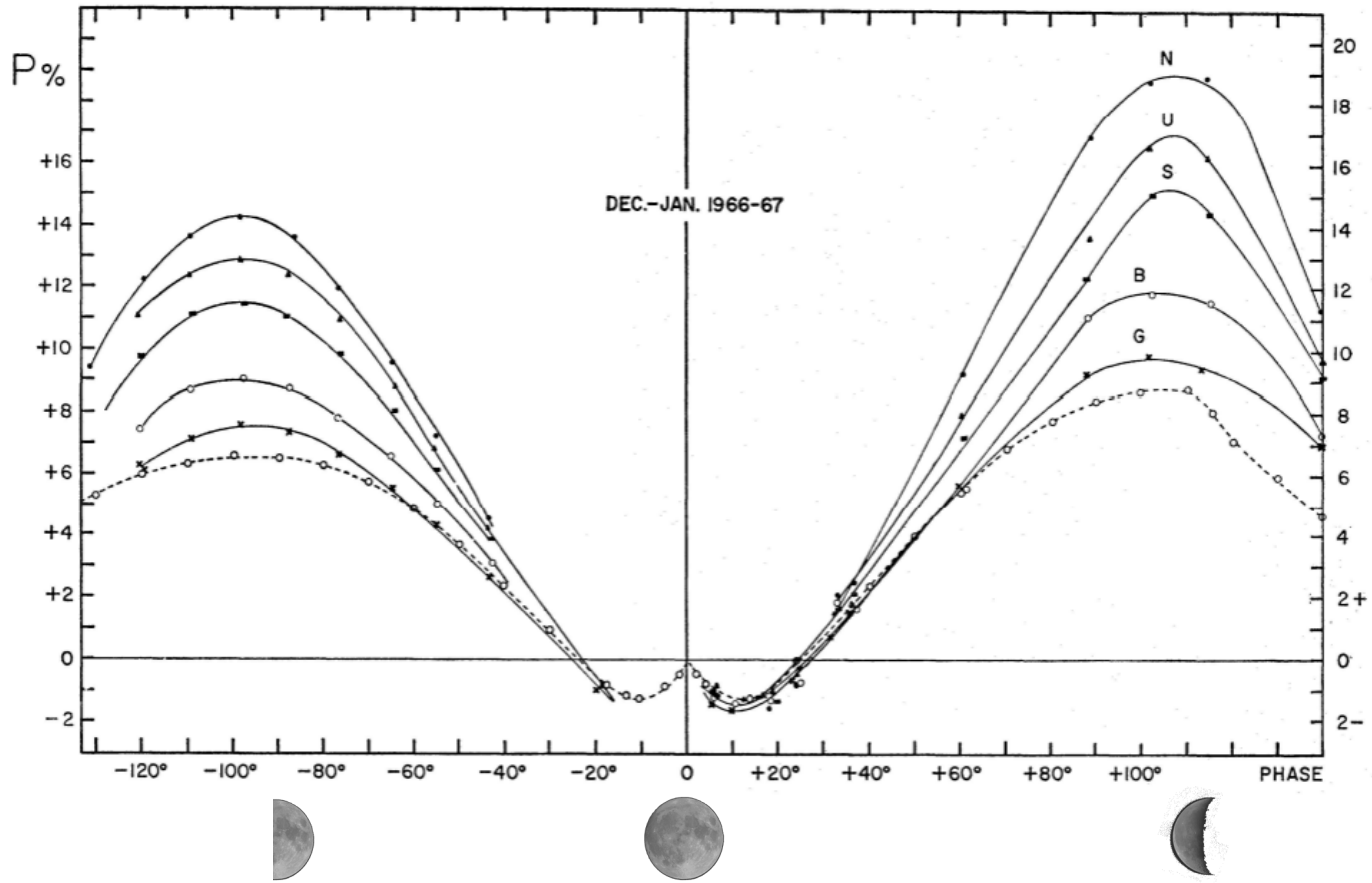


300-mm lens images

- More dark surface area for waning phases

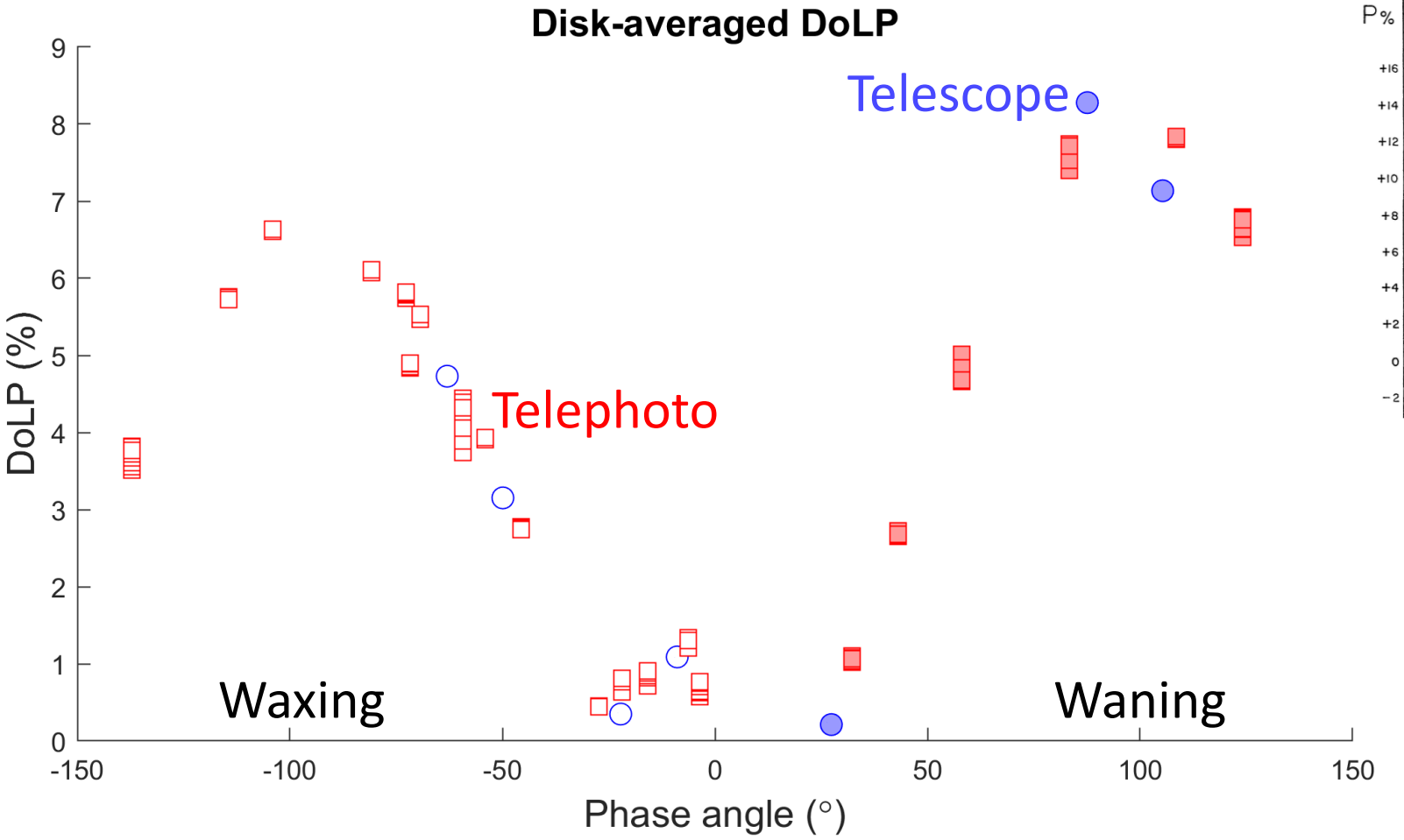


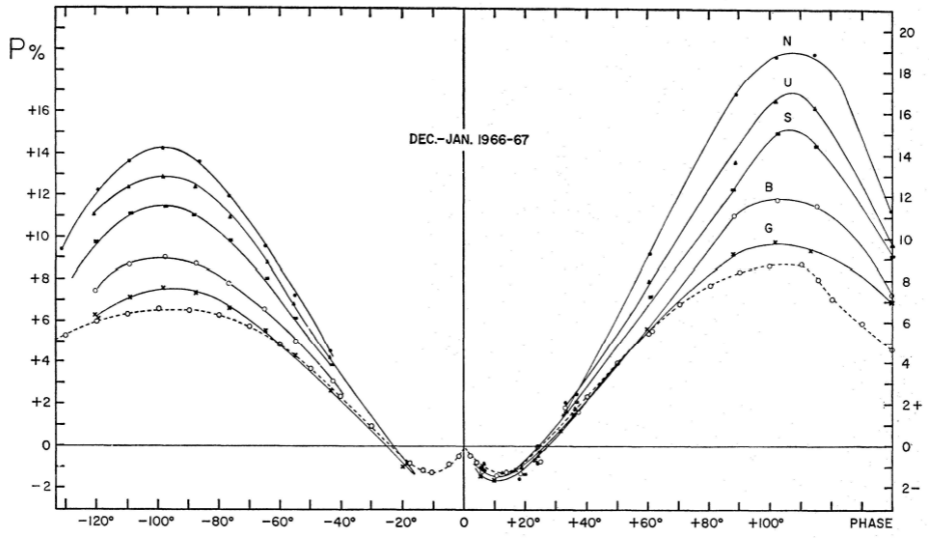
Previous disk-averaged measurements



Bands from 320-600 nm
Coyne and Pellicori, 1970

Polarization state vs phase angle





$$DoLP = \frac{\sqrt{S_1^2 + S_2^2}}{S_0}$$

$$DoLP = \frac{S_1}{S_0} = \frac{I_\perp - I_\parallel}{I_\perp + I_\parallel}$$

Conclusions

- Recorded spatially resolved images and disk-averaged values of DoLP across many phase angles
- Recorded disk-average DoLPs in a VNIR spectral band
- Recorded images of AoP

References

- E. Venkatesulu and J. A. Shaw. Measuring the spectral response of a divisionof-focal-plane polarization imager using a grating monochromator. Applied Optics, 61(9):2364–2370, 2022.
- G. V. Coyne and S. F. Pellicori. Wavelength dependence of polarization. xx. the integrated disk of the moon. The Astronomical Journal, 75:54, 1970.

Acknowledgments

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