Measuring the polarization of disk-integrated lunar reflectance in the middle ultraviolet

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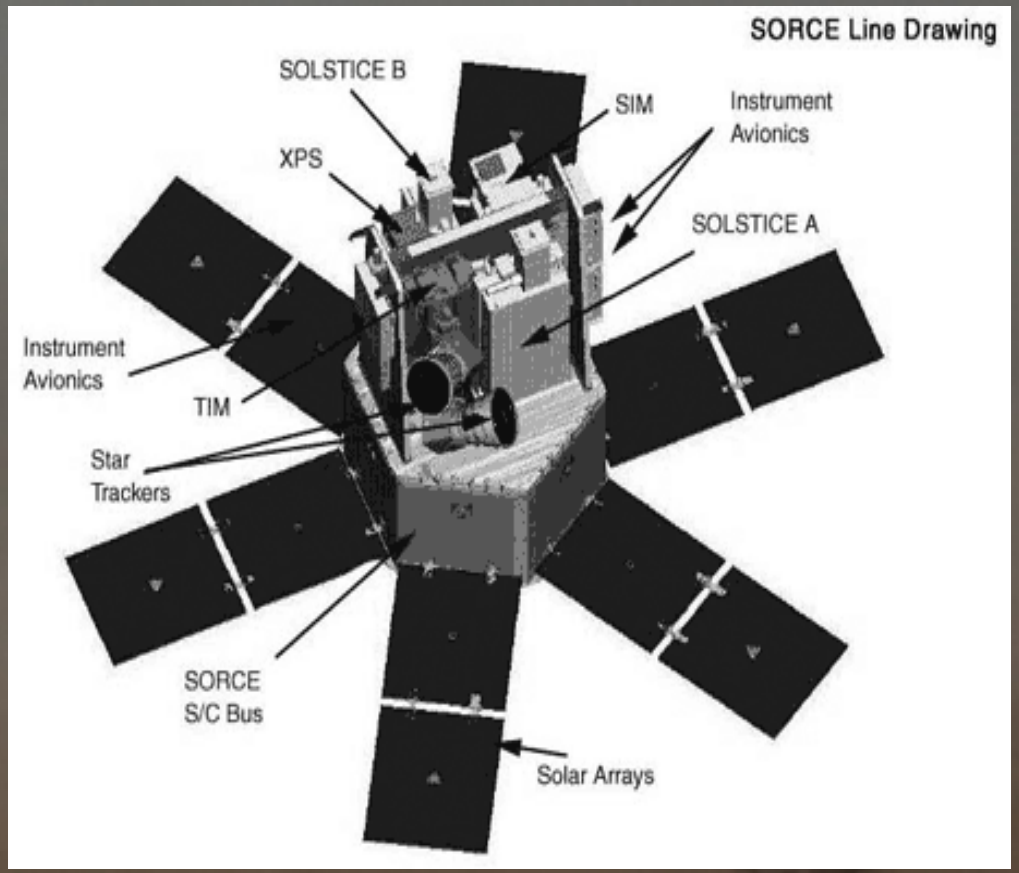
Overview

- **Background**
  - *Key definitions*
  - *What we were trying to find*
- **Analysis**
  - *Methods used to address problem*
- **Conclusions**
- **Future Steps**

Overview of SORCE

- SORCE = SOLar Radiation and Climate Experiment
- Specifically looking at the data from the the SOLSTICE (SOLar-STellar Irradiance Comparison Experiment) instruments



Motivation for SORCE

- NASA-sponsored; launched in 2003
- Provides measurements of incoming x-ray, ultraviolet, visible, near-infrared, and total solar irradiation.
- This data addresses long-term climate change, natural variability and enhanced climate prediction, and atmospheric ozone and UV-B radiation
- 4 instruments: Spectral Irradiance Monitor (SIM), Solar Stellar Irradiance Comparison Experiment (SOLSTICE), Total Irradiance Monitor (TIM), and XUV Photometer System (XPS)

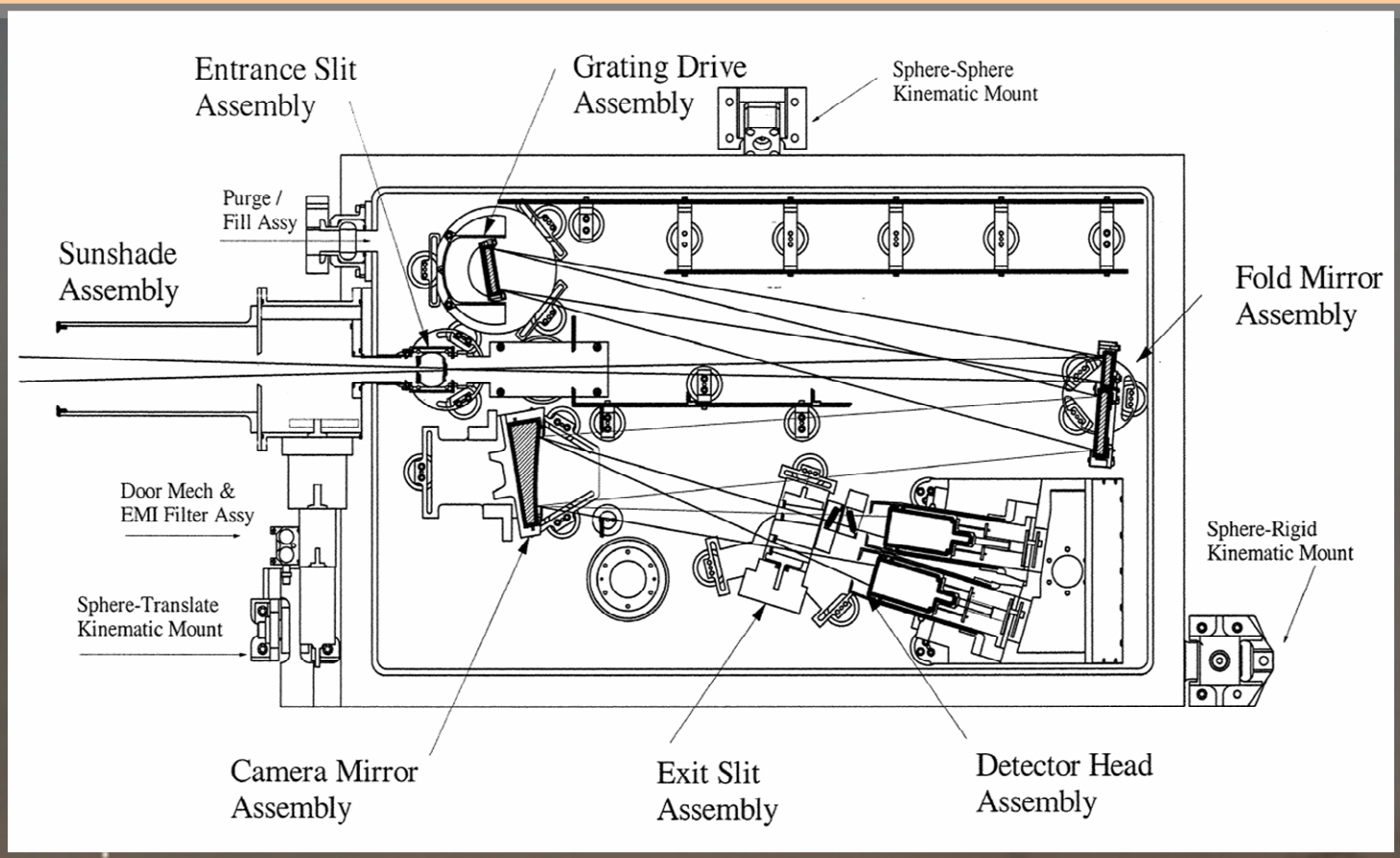
SOLSTICE (A and B)

- Purpose of SOLSTICE = one of four instruments on SORCE
- Measures the ultraviolet (from ~115-310 nm), with a 2.2 nm resolution in MUV (180-310 nm) stellar mode and 0.1 nm resolution in solar mode

SOLSTICE set-up

- Grating spectrometer
- Field of view = ~2 degrees; entire moon is shown
- Detector is a photomultiplier tube; measures one wavelength at a time by changing the rotation of the grating
  - Plane waves, incident on the grating, are diffracted into zero and first order
  - Rotating the grating causes the diffraction angles to change

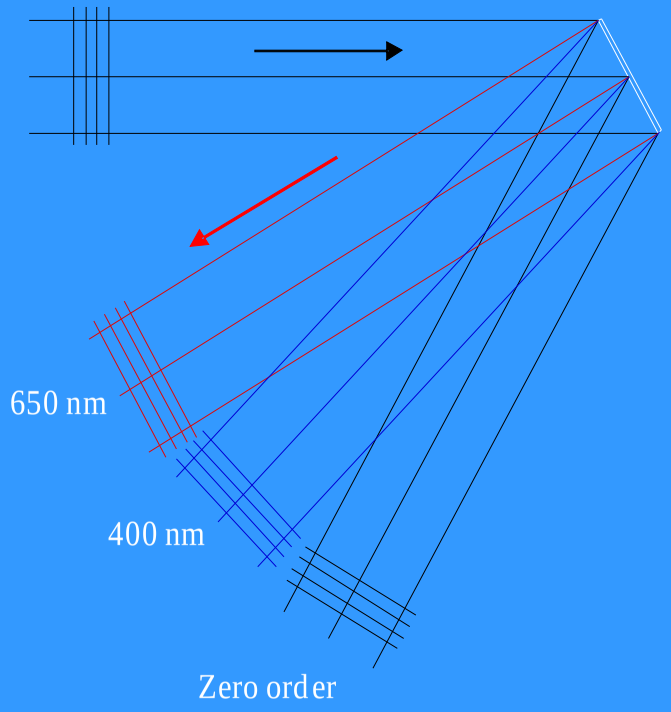
Internal workings of SOLSTICE



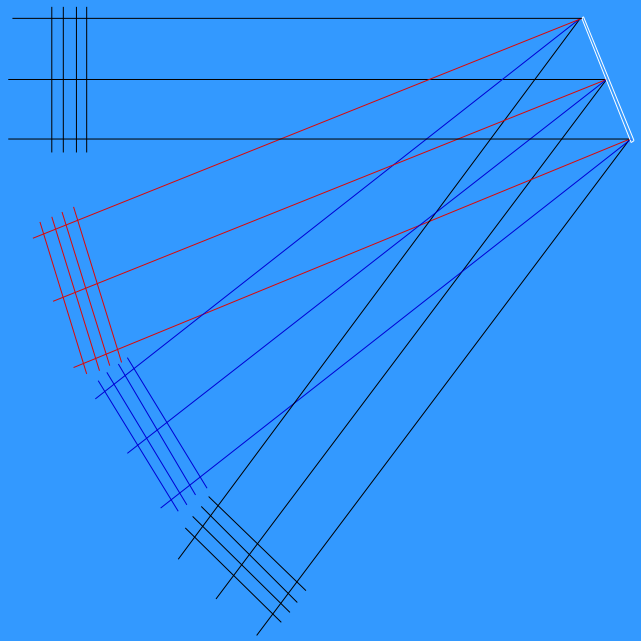
Plane grating monochromator design – uses one concave mirror to collimate and focus the spectrum. Only light that leaves the grating at the correct angle will pass through the exit slit.

Reflection Grating, ctd.

Plane waves, incident on the grating, are diffracted into zero and first order

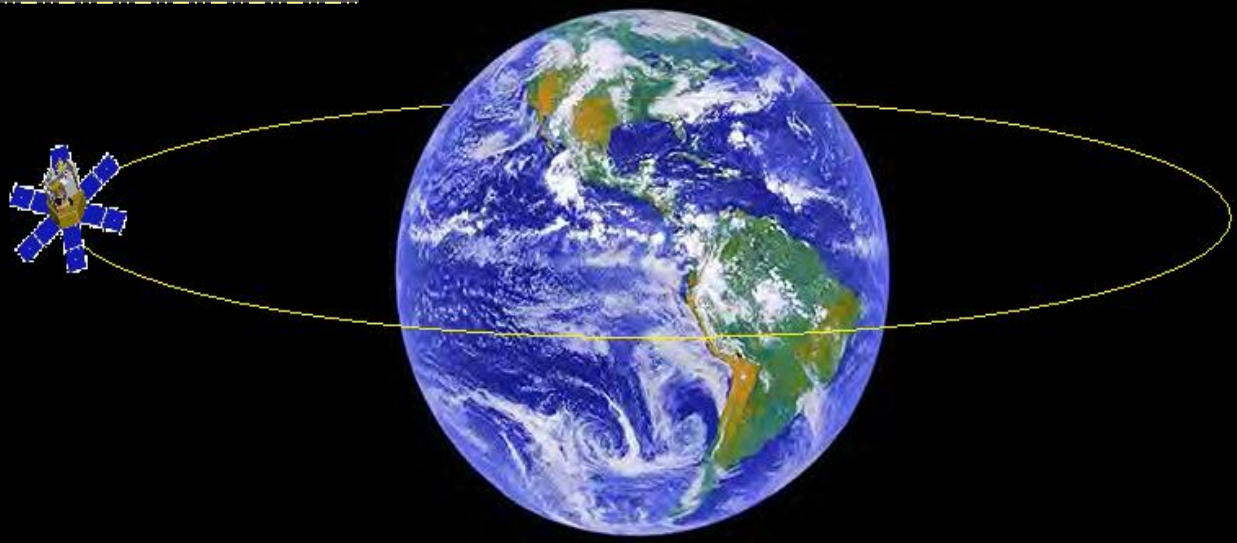


Rotating the grating causes the diffraction angle to change



Orbit of spacecraft

645 km,
40° inclination,
90 min rotation period



* *NOTE: not to scale*

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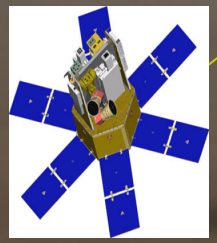
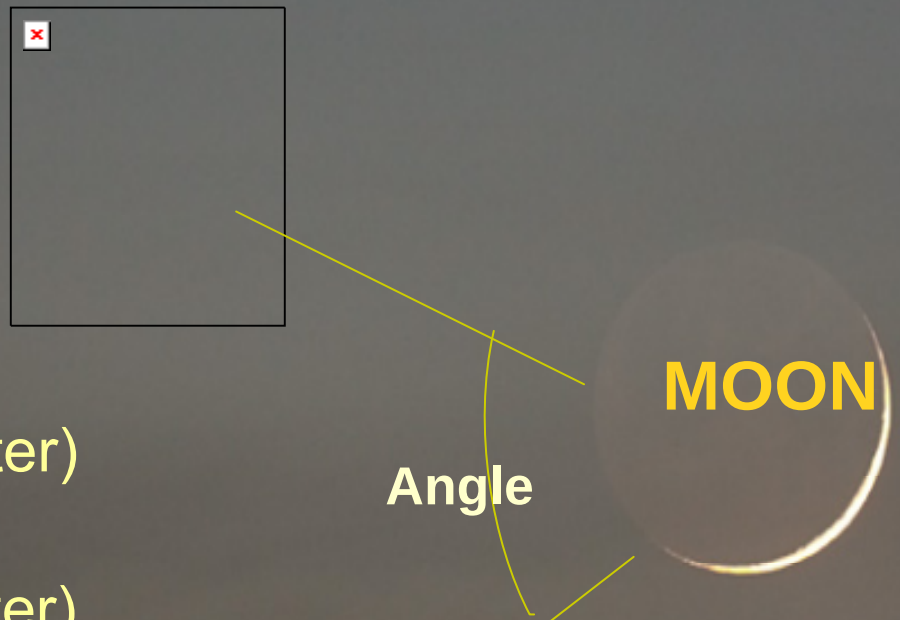
Phase angle

- = 0 (full moon)
- = 180 (new moon)
- = -90 (waxing quarter)
- = +90 (waning quarter)





SOLSTICE Lunar Measurements

- Reasons why SOLSTICE lunar measurements are unique:
  - Broad phase angle coverage (0-170 deg.)
  - Full-disk measurement – always observing the whole moon
  - The lunar UV reflectance is relatively unexplored
  - Since the moon and the sun were observed with the same instrument, reflectance wouldn't depend on sensitivity

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Questions to address:

Can we measure the polarization of lunar irradiance in the ultraviolet?

Polarization

- Definition: the fractional linear polarization of a beam of light from a body is defined as:

$$P_b = \frac{I_s - I_p}{I_s + I_p}$$

- Where Is is the magnitude of the beam which is oriented such that the electric vector is perpendicular to the scattering plane, and Ip is the magnitude of the beam which is pointed with the electric vector parallel to the scattering plane

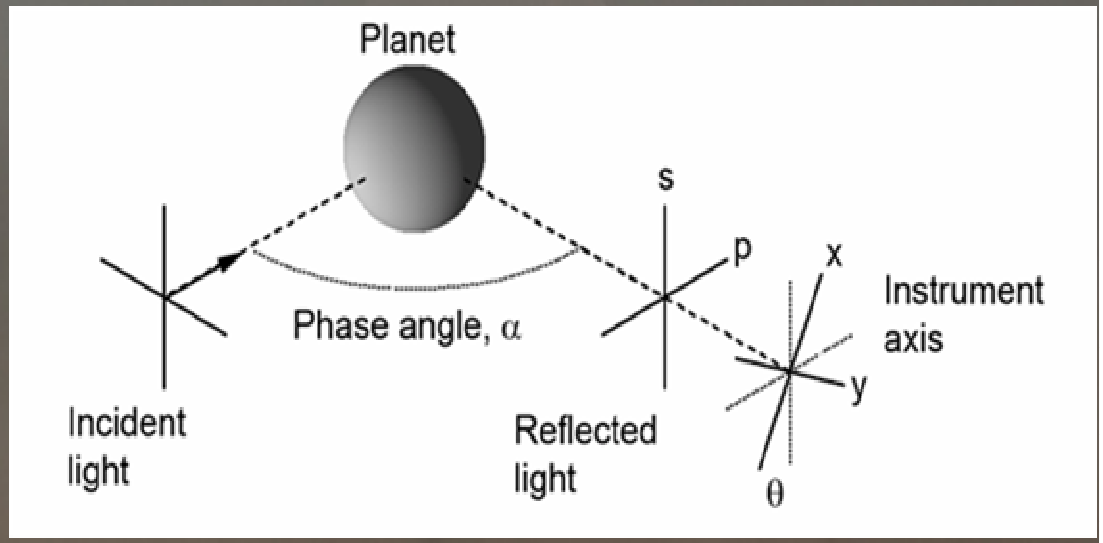
- Polarization ranges from -1 to +1, with 0 = unpolarized light

Photometry

- The study of the variation in the brightness of a surface or body as a function of illumination and viewing geometry
- Mathematical functions are used to model this variation
- Essential for intercomparing the reflectance of one surface to another for different viewing geometries

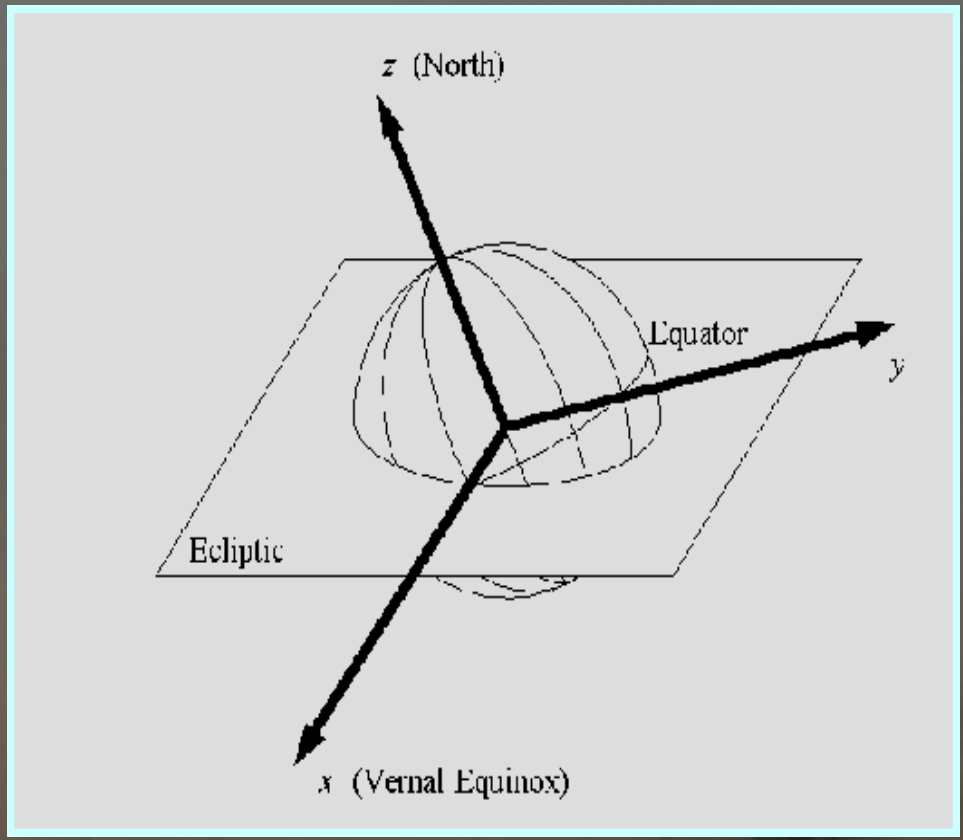
Scattering Plane

- Examining the geometry of the observations
- Derived the vector normal to the scattering plane between the Sun-Moon-SORCE (the source, the target, and the observer)
- Polarization ranges from -1 to +1, with 0 = unpolarized light



ECI Coordinates

- Earth-Centered Inertial
- Original data provided vectors for the sun, the moon, and the SORCE spacecraft, but the orientations of the vectors were not aligned on similar axes



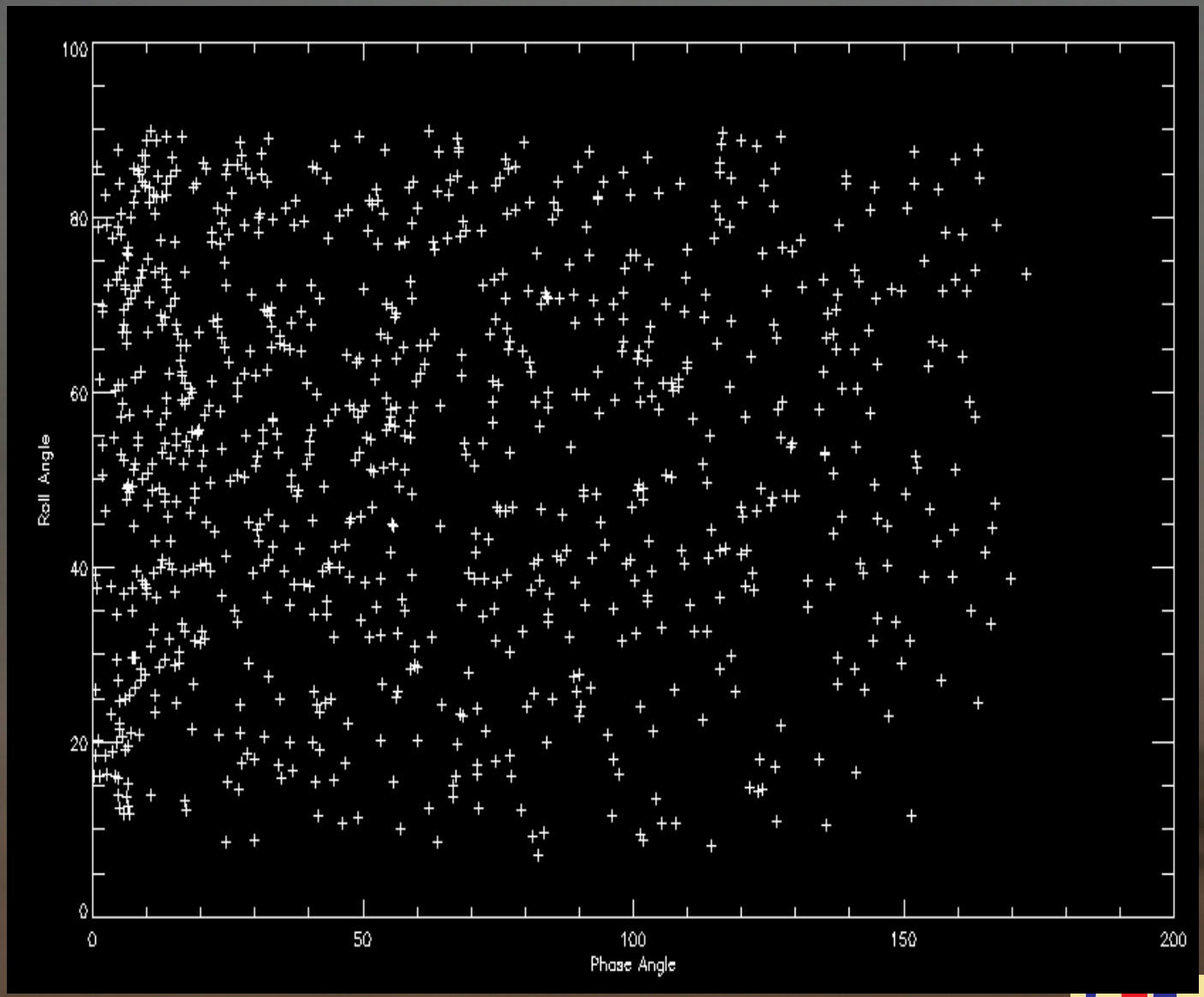
How are effects measured?

- Effects are measured by rotating a polarizer with respect to the scattering plane and observing changes in modulation of signal
- Wide range of phase angles for a given roll angle ⟶ means we can measure polarization

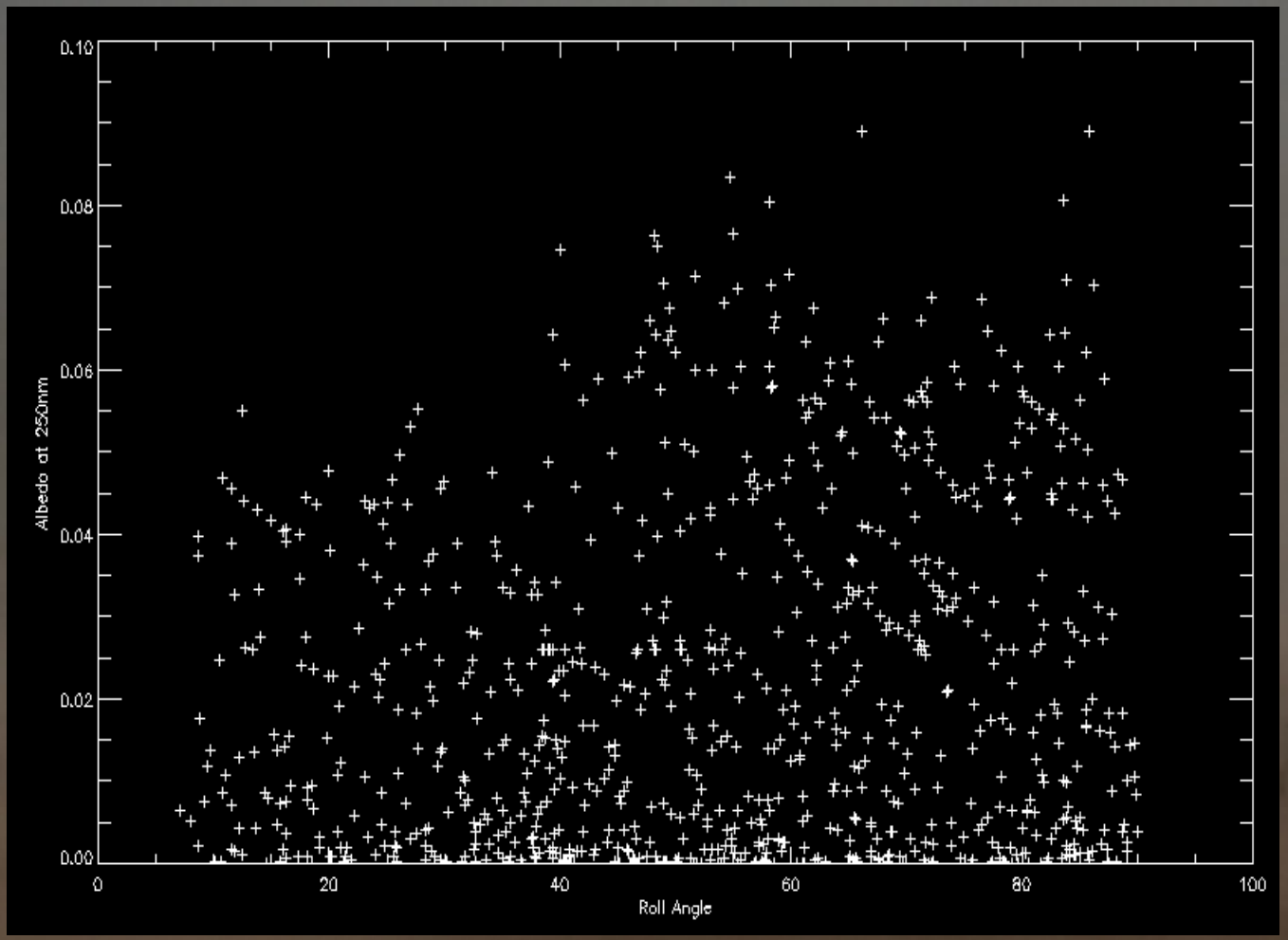
Roll angle for spacecraft

- Derived by obtaining the cross product of two vectors (same as phase angle)
- Where is it pointed?
  - Spacecraft can point its axis (any direction) ⟶ defined z-axis
  - Spacecraft can roll about its z-axis
  - All positions are stored in database as vectors (with direction & magnitude)
  - Earth-Centered Inertial (ECI) is fixed with respect to celestial sphere, i.e. stars are inertial targets

Broad range of phase angles



Albedo at 250nm vs. roll angle



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Why wavelengths were chosen

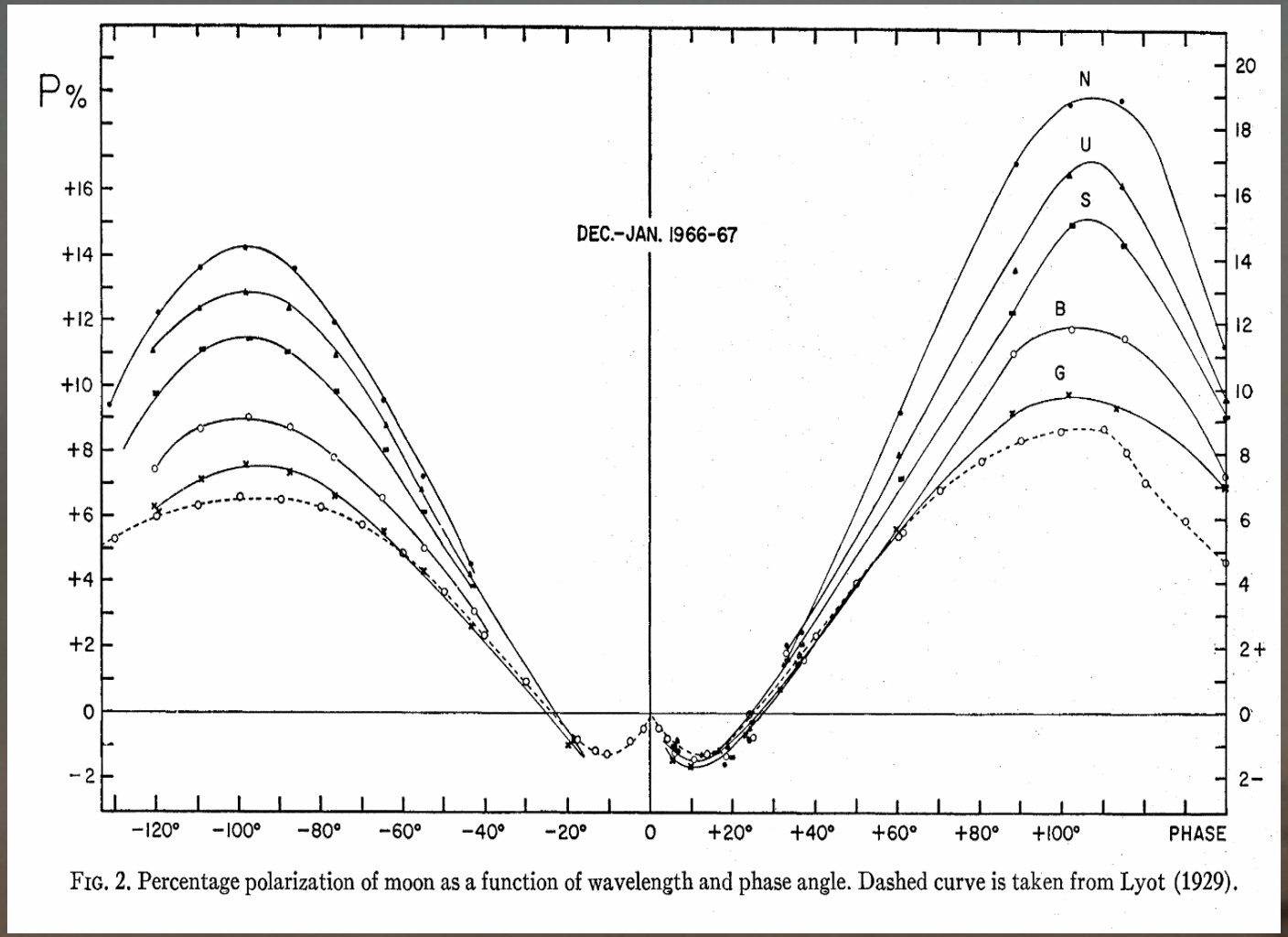
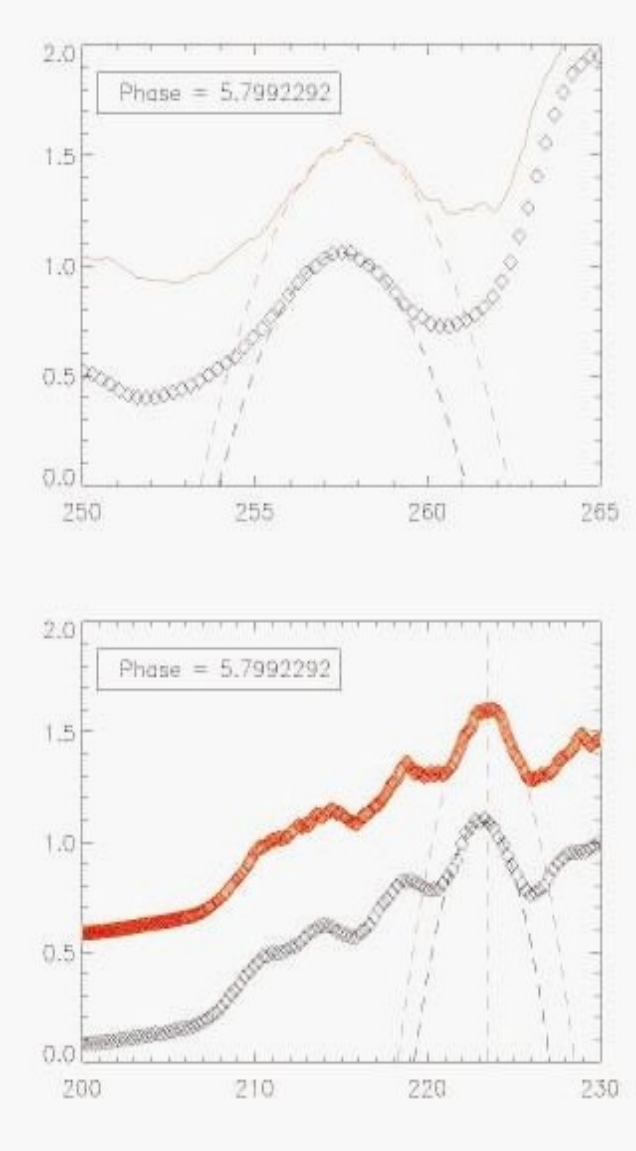


FIG. 2. Percentage polarization of moon as a function of wavelength and phase angle. Dashed curve is taken from Lyot (1929).

Polarizer at 250 (sensitive to polarization at longer wavelengths)

No spectral lines @ 195 (doesn't matter what roll angle is)

Ratio at 250 nm and 195 nm



Sun's spectrum is normalized with a Gaussian fit

Ratio of sun vs. moon is the reflectance

Angles were chosen because the instrument is sensitive to polarization at 250nm, and not at 195 nm

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What we expected to find

- SOLSTICE is a weak polarizer, and the plots of reflectance vs. roll angle should show variation if there is a detectable polarization effect
- The slope of the line is a measurement of the magnitude of polarization; that slope is then plotted against phase angle
- Malus's Law = states that when a perfect polarizer is placed in a polarized beam of light, the intensity (I) is given by:
- Where Im = initial intensity, and theta is the light's initial polarization direction and the axis of the polarizer

$$I = I_M \cos^2 \theta$$

Lunar polarization

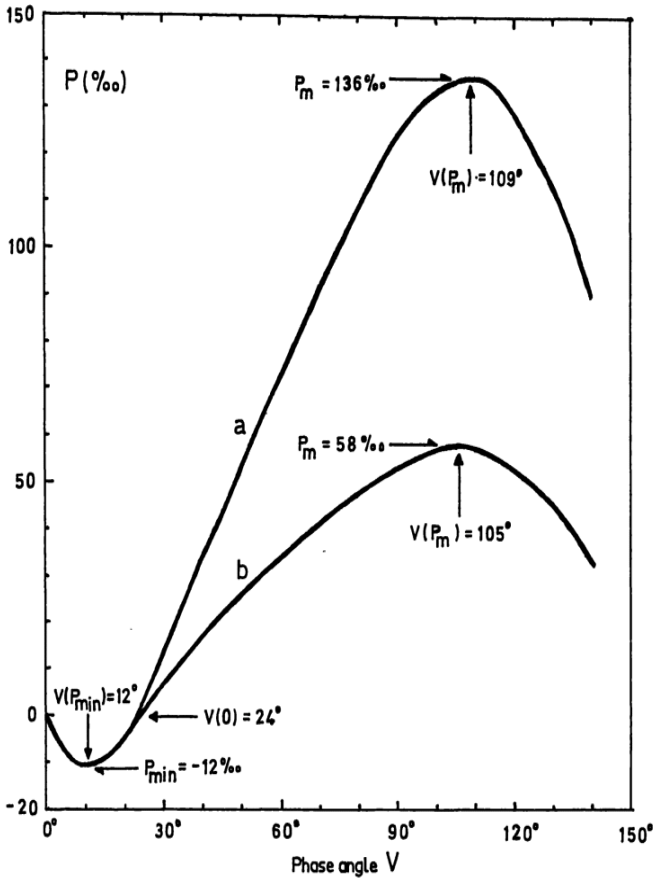
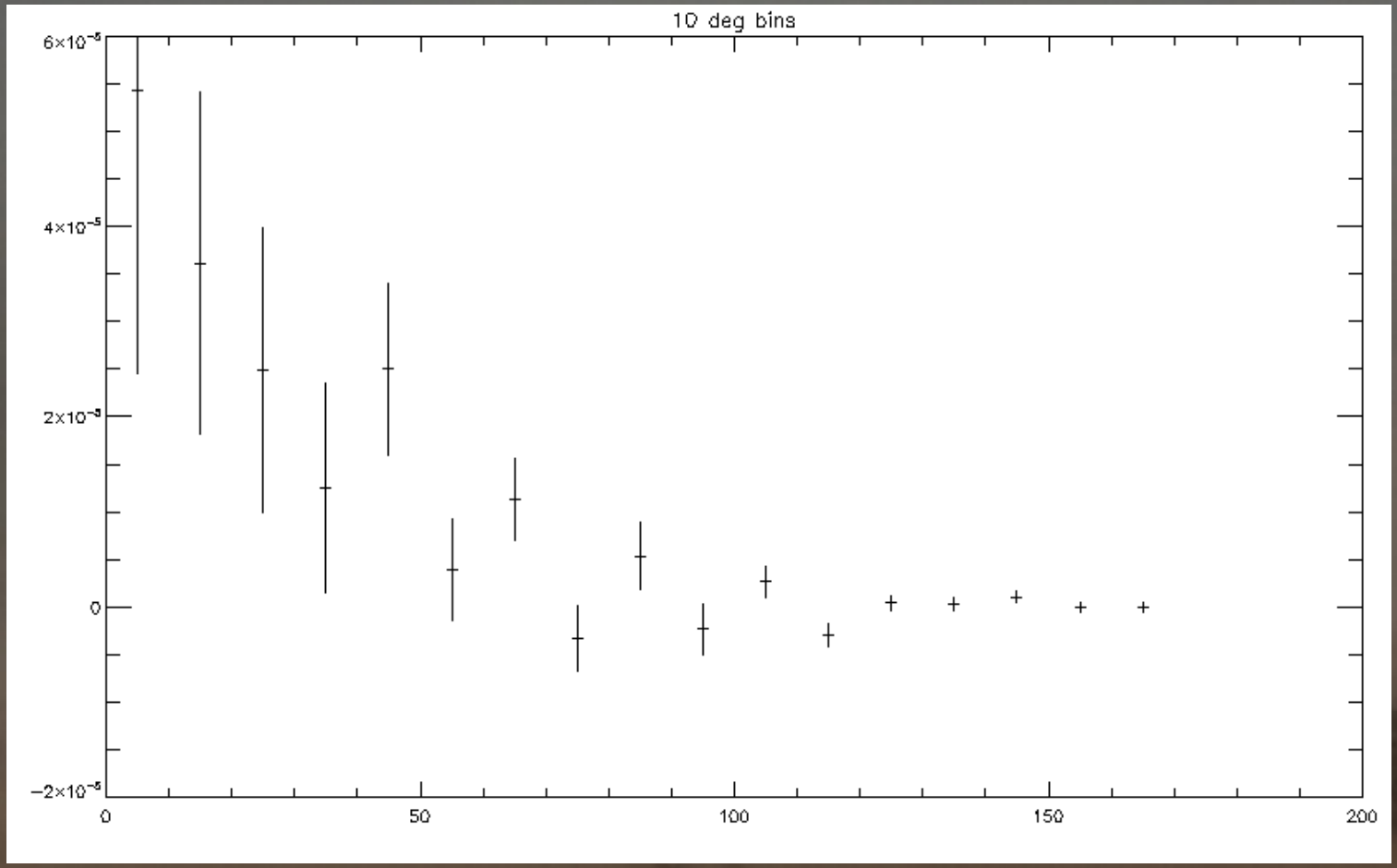


Fig. 1. Typical curves of polarisation (amount of polarisation P versus phase angle V) for two lunar terrains (orange light $\lambda = 0.60\ \mu$). a Mare: Area D 7, Oceanus Procellarum. $A = 0.063$. b Continent: Area D 8, Krüger. $A = 0.117$

- Nearly all airless solar system bodies exhibit this shape of polarization response [Hapke, 1993].
- The curves are characterized by a few obvious parameters (P is polarization, V is phase angle):
- P_{max}, V_{max}
- P_{min}, V_{min}
- V_i (inversion angle)
- h_i (slope at inversion angle)
- This shows that the magnitude of the polarization is inversely proportional to the albedo (thus, the dark mare exhibit a large polarization).

What we found... at first



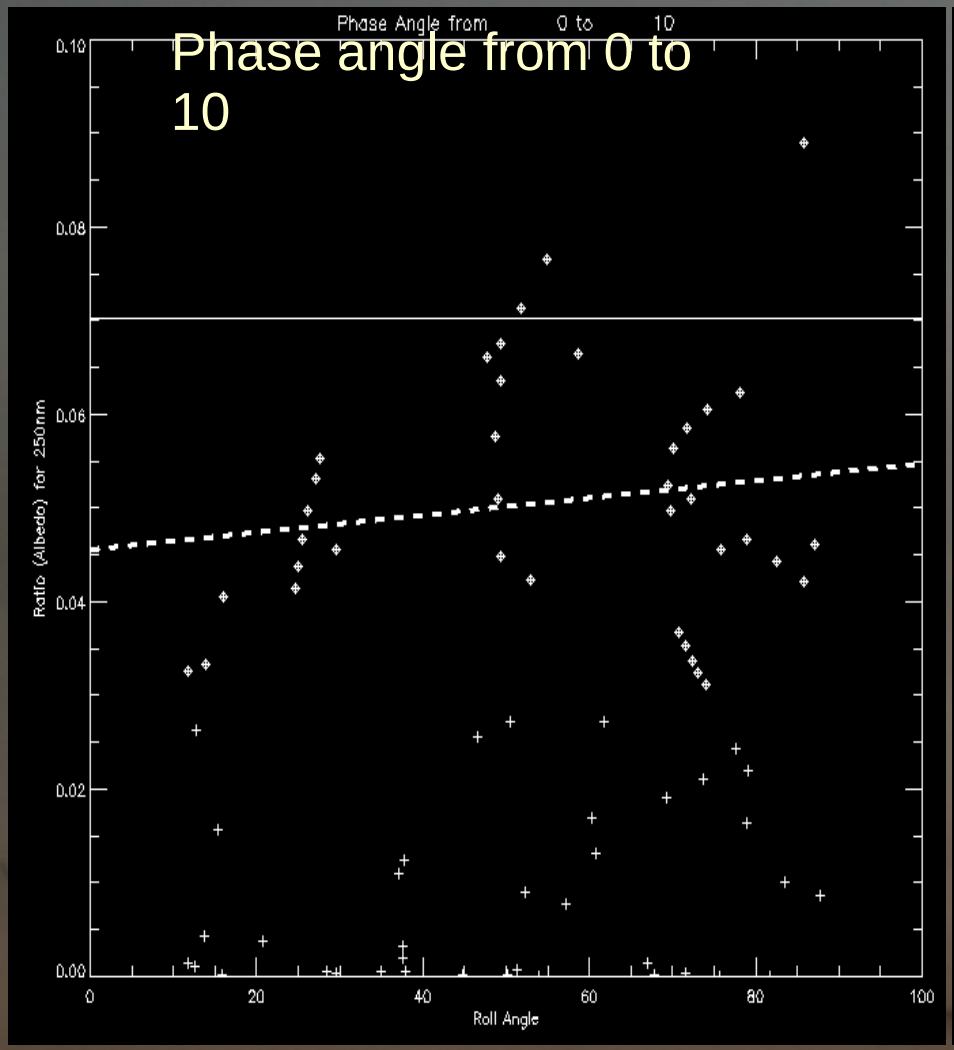
Reducing uncertainty of slope

- Since roll angle data points should theoretically be mirrored across the 90 degree mark, a command was input to reflect and combine the two branches (doubling the data, and hopefully reducing the noise)

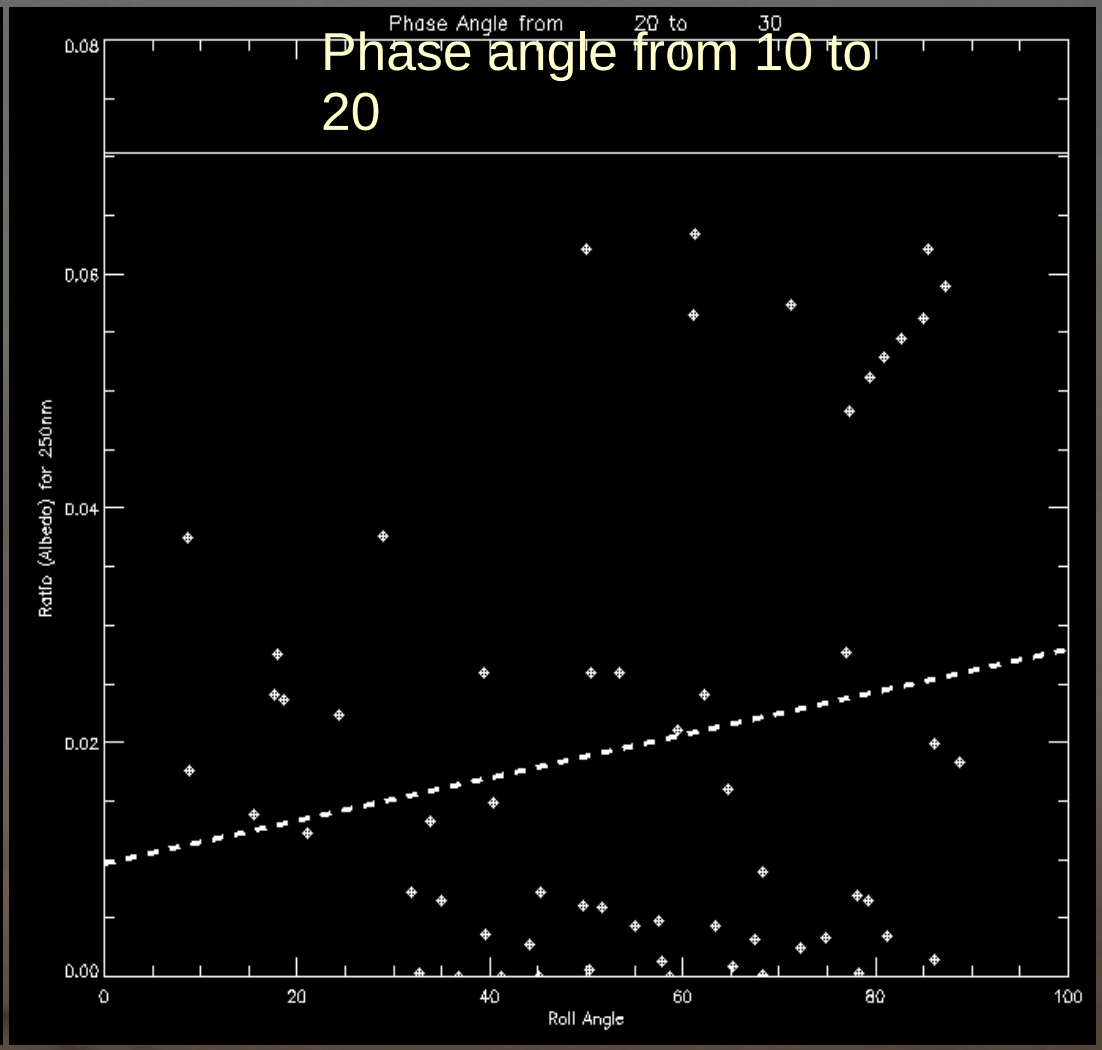
Data filtering

- Filtered outliers – points greater than 2 sigma from the mean
- Filtered obviously suspicious data
- Tried parsing various intervals of degrees for the x-axis (10 degree intervals, 20 degrees, 30 degrees, etc.)
- Percentage of polarization

Examples of filtering



Phase angle from 0 to 10



Phase angle from 10 to 20

Roll angle vs. Albedo at 250 nm

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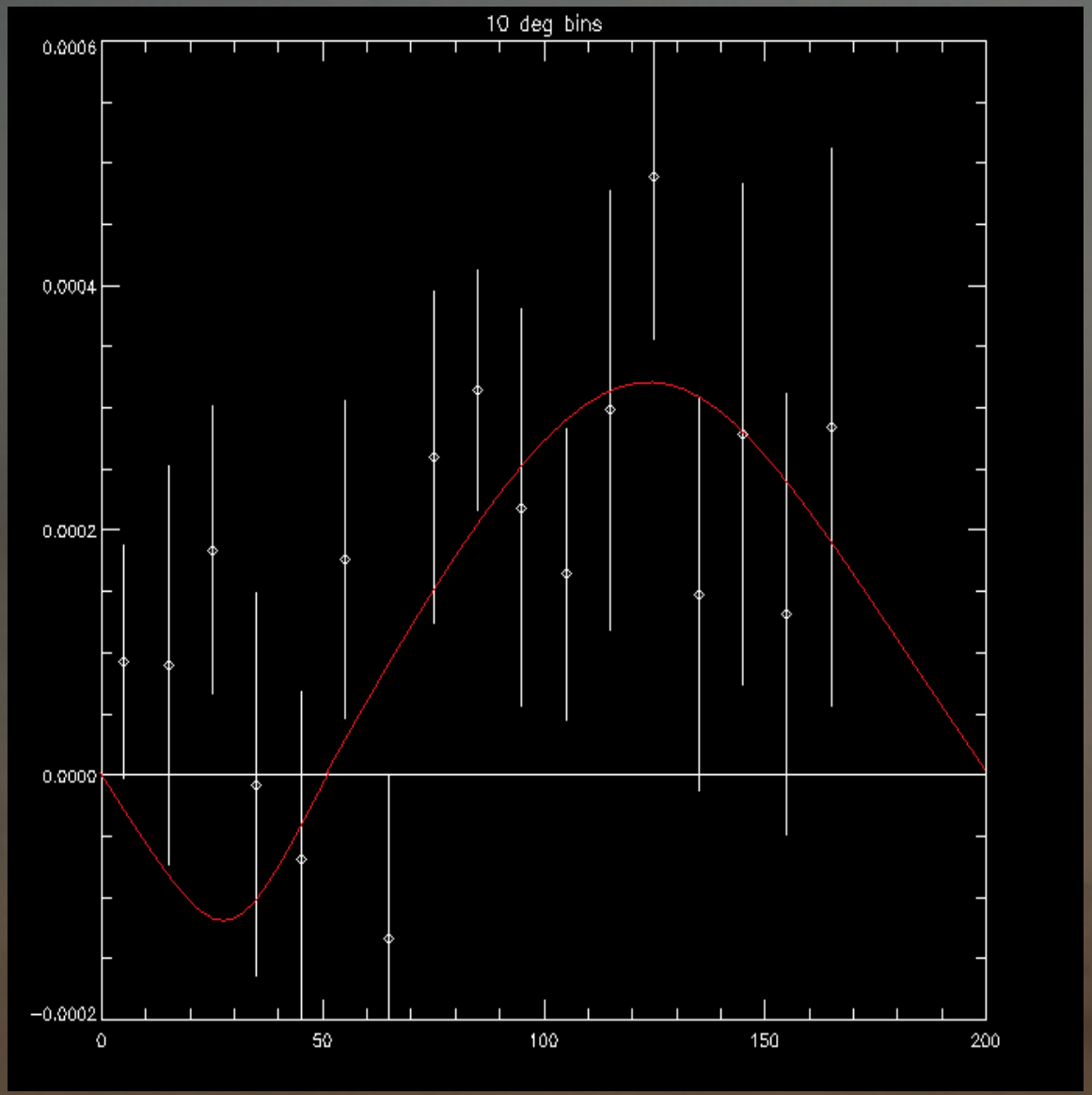
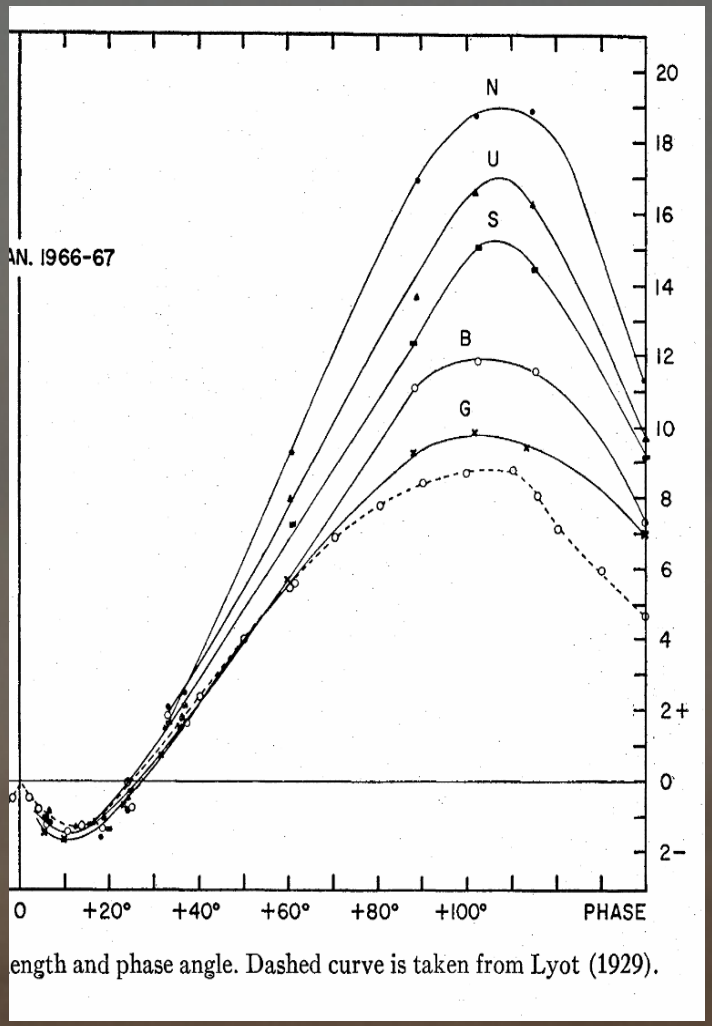
Results: Slope vs. Phase Angle





ength and phase angle. Dashed curve is taken from Lyot (1929).

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Questions

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Acknowledgments

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