LOUPE

Lunar Observatory for Unresolved Polarimetry of Earth

Daphne Stam

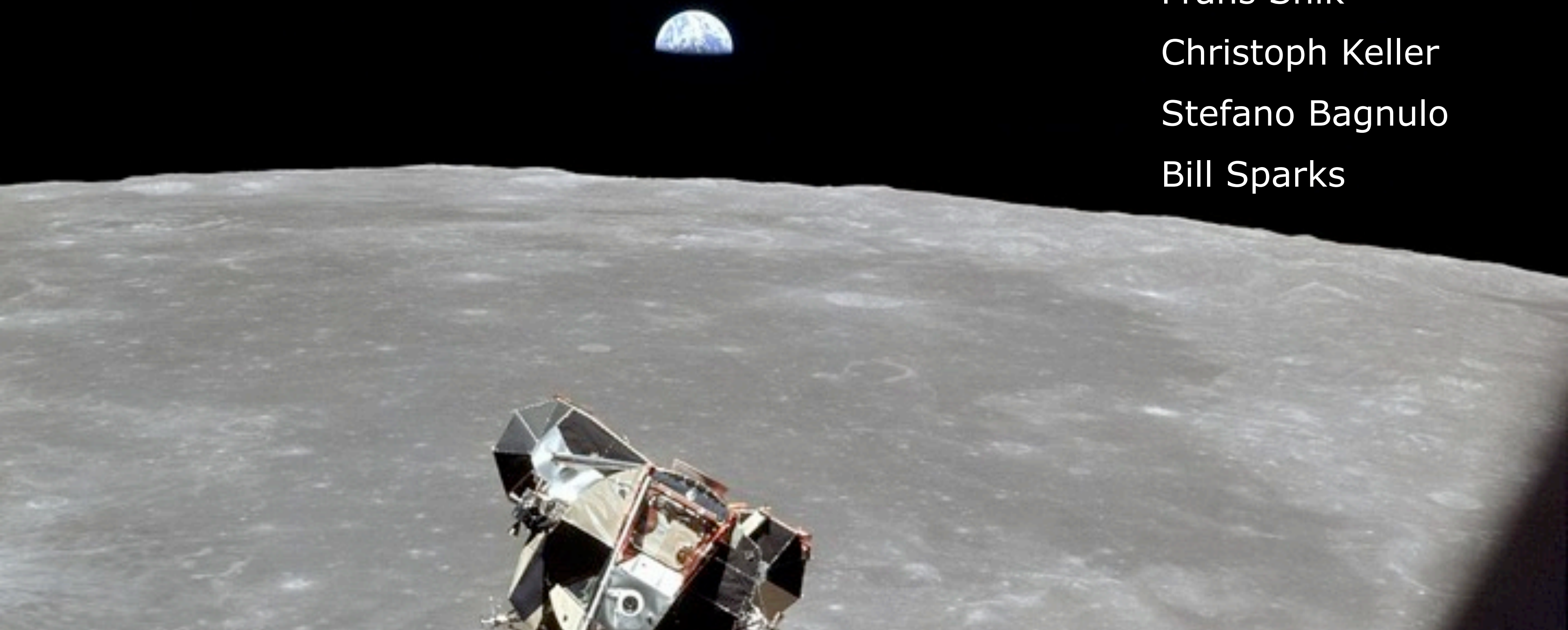
Theodora Karalidi

Frans Snik

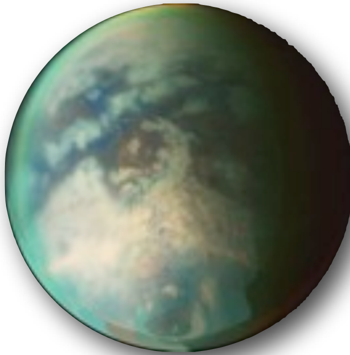
Christoph Keller

Stefano Bagnulo

Bill Sparks

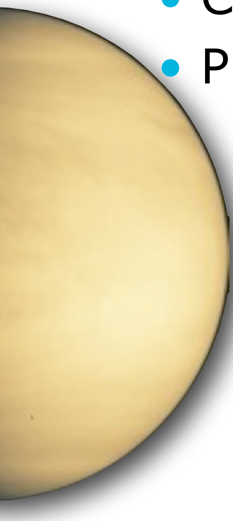


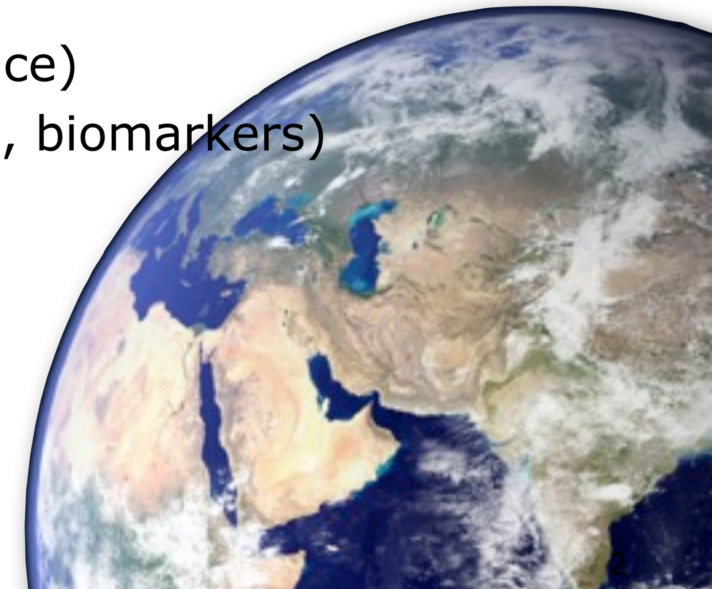
Characterizing terrestrial exoplanets



What would we like to know about small, rocky planets?

- Size (composition, plate tectonics)
- Rotation period
- Obliquity angle (seasons)
- Thickness atmosphere (surface pressure)
- Composition atmosphere (CO2, N2, O2, trace gases ...)
- Composition and distribution of clouds (altitude, coverage)
- Surface coverage (continents, oceans)
- Composition of the surface (sand, water, ice)
- Presence of life as we know it (vegetation, biomarkers)





Needed for exoplanet characterization

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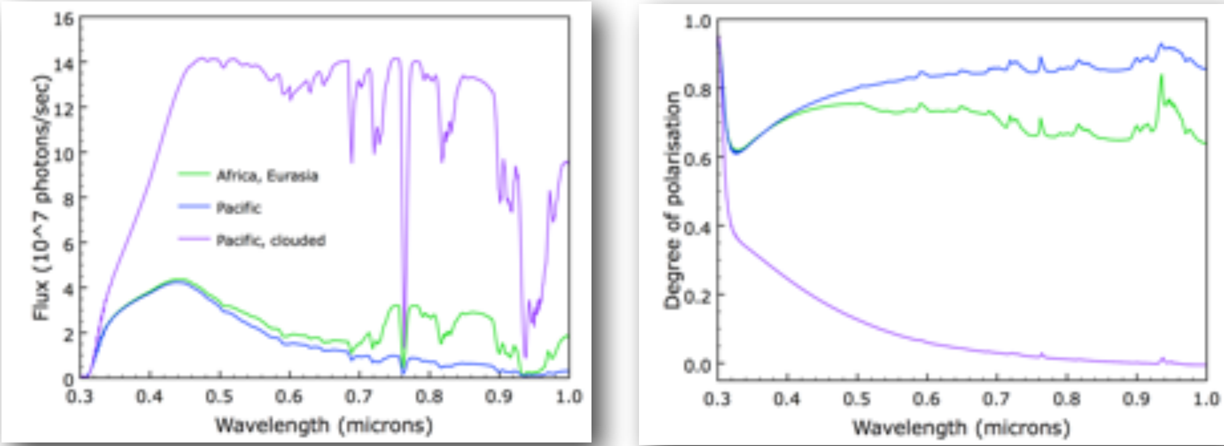
Spectral total and polarized fluxes ...



Wednesday, October 23, 13

Needed for exoplanet characterization

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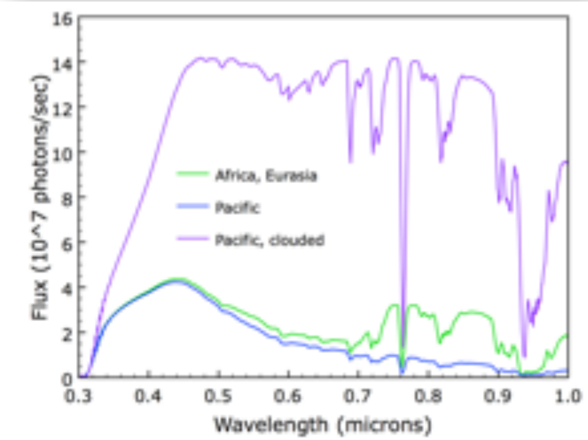
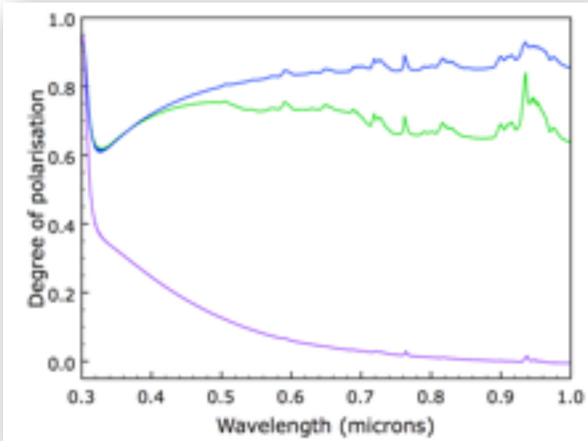
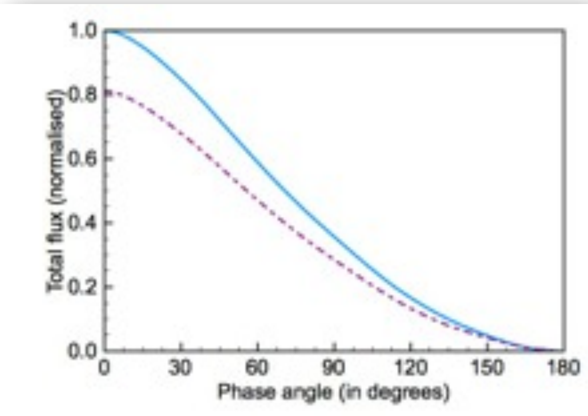
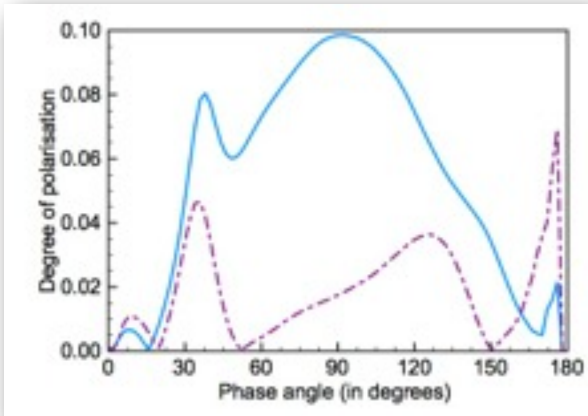
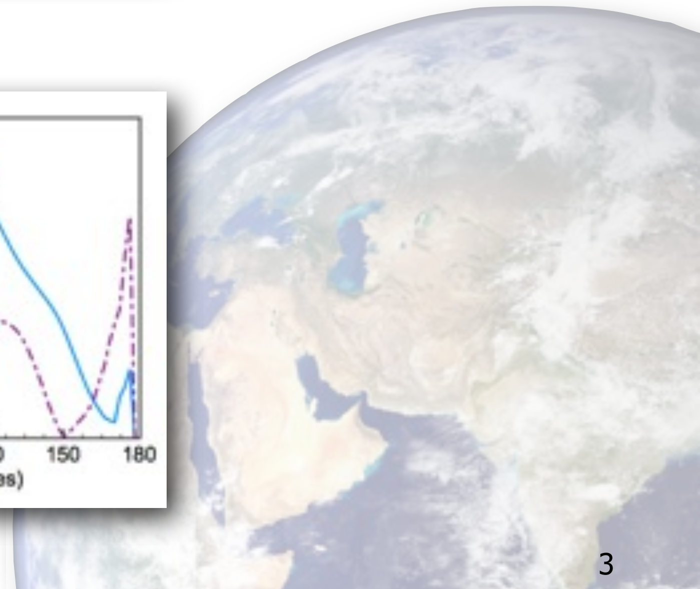




... as functions of the phase angle



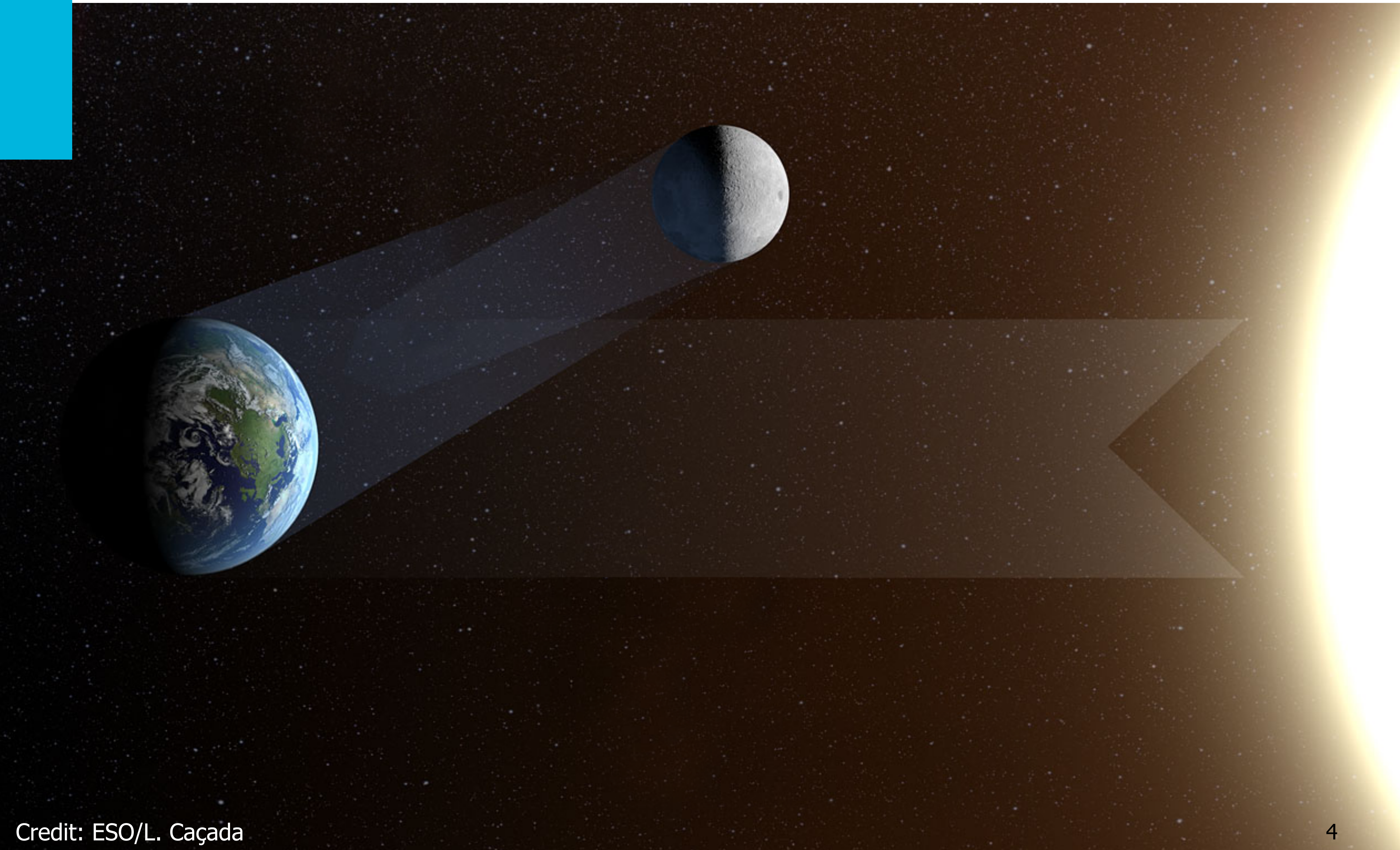




Needed for exoplanet characterization

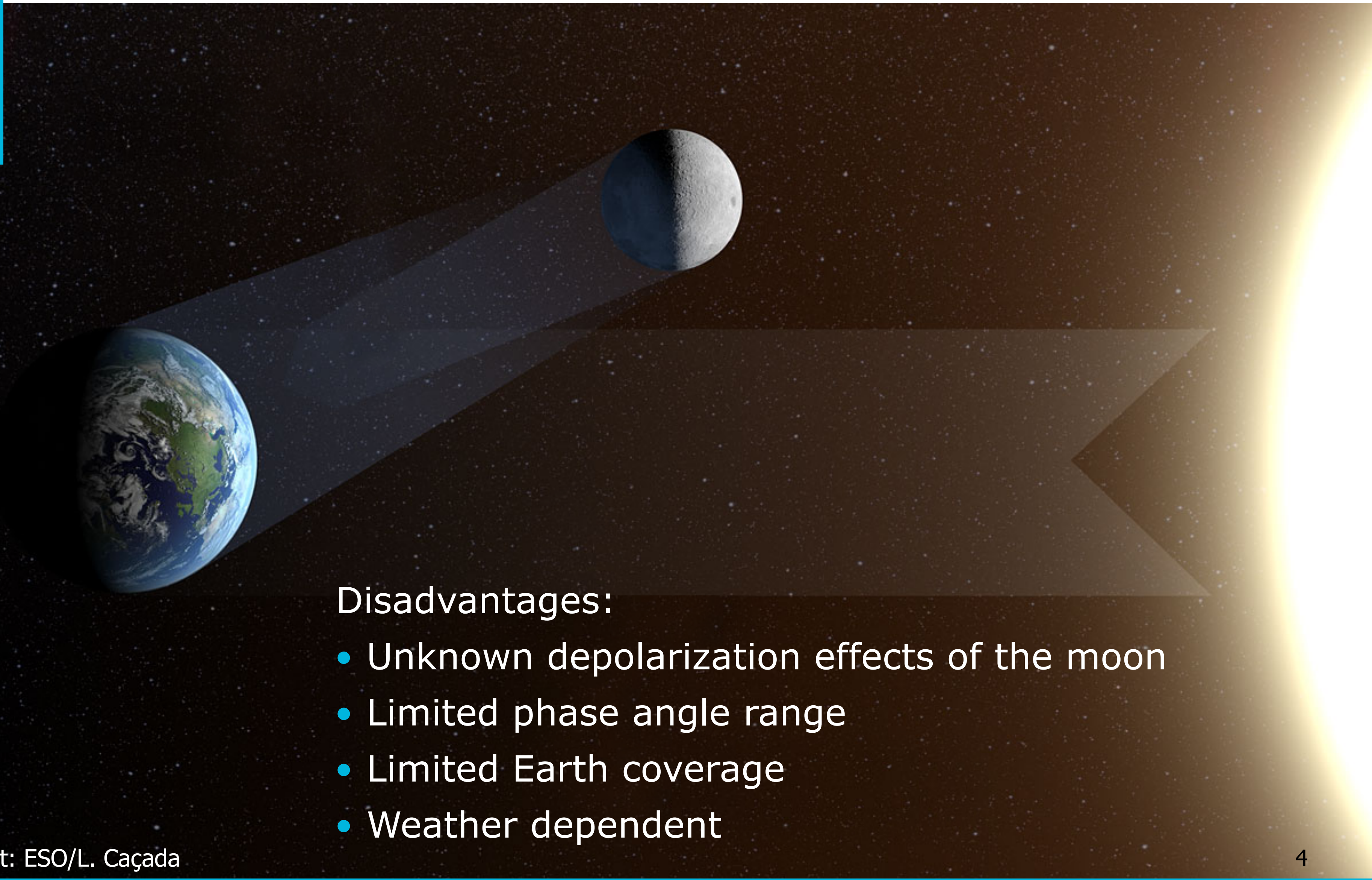
Spectral total and polarized fluxes ...

Earthshine observations



Credit: ESO/L. Caçada

Earthshine observations

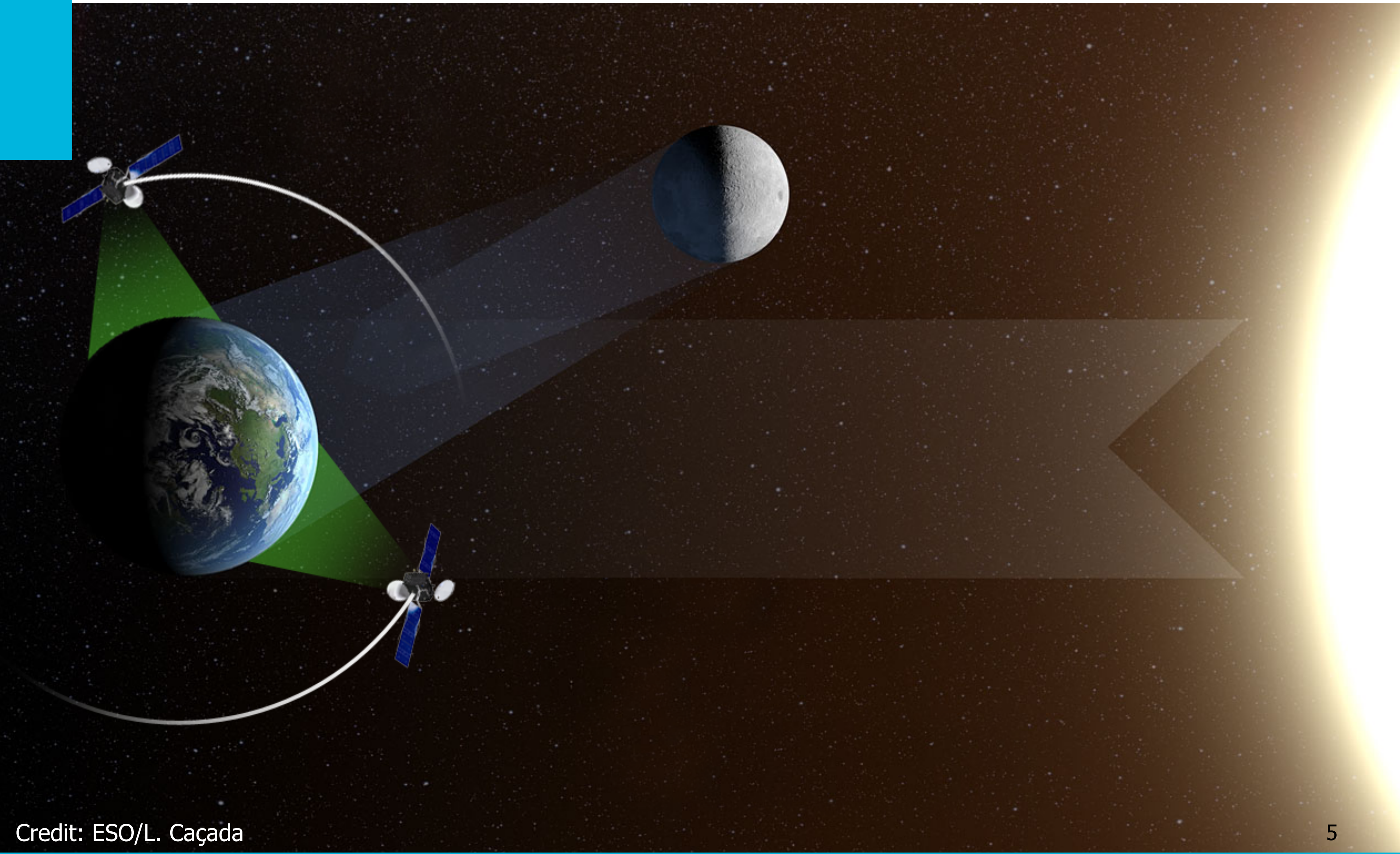


Disadvantages:

- Unknown depolarization effects of the moon
- Limited phase angle range
- Limited Earth coverage
- Weather dependent

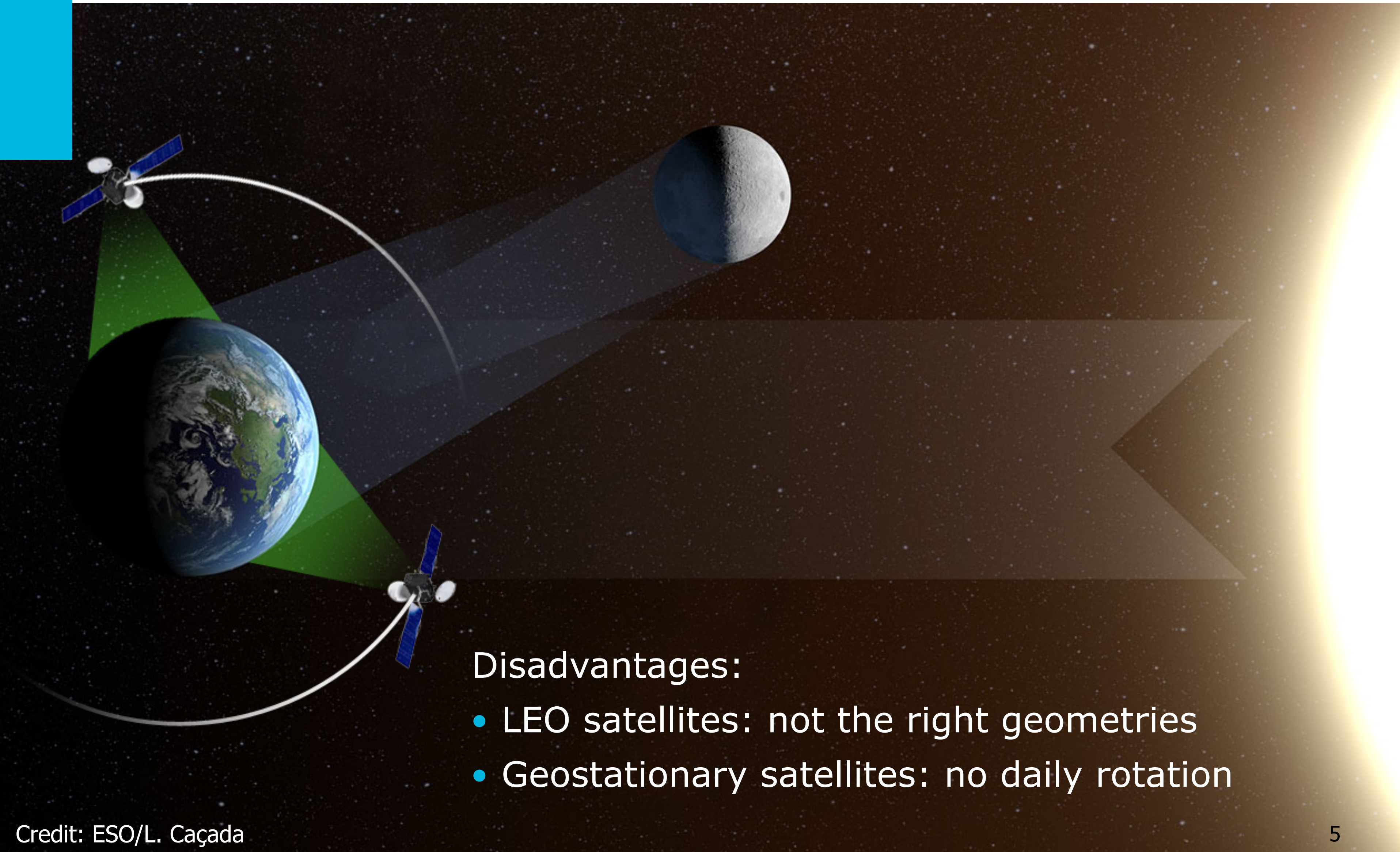
Credit: ESO/L. Caçada

Earth observations from satellites



Credit: ESO/L. Caçada

Earth observations from satellites



Disadvantages:

- LEO satellites: not the right geometries
- Geostationary satellites: no daily rotation

Credit: ESO/L. Caçada

LOUPE scientific goals

From the moon, LOUPE will gaze continuously at the Earth, measure the flux and polarization of reflected sunlight, to provide benchmark data for exoplanet characterization.*

*LOUPE-data would also be interesting to Earth-scientists

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Advantages of being on the moon:

- It is outside the Earth’s atmosphere
- The moon is invisible
- The whole Earth is visible (~2^{o} FOV)
- The Earth’s daily rotation can be monitored
- The Earth can be observed at all phases
- The Earth can be observed throughout the seasons
- The Earth remains at about the same location in the sky

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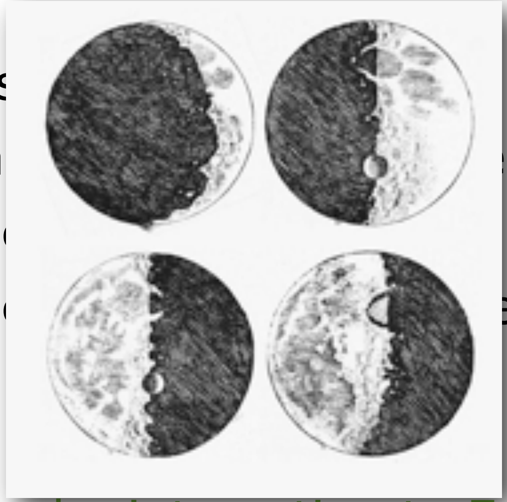

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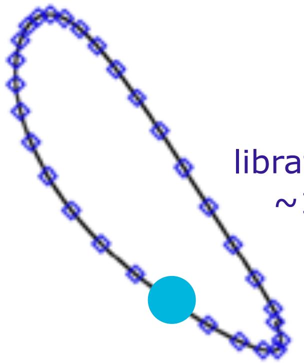

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The Earth as seen from the moon

Credit: Thijs Krijger (SRON)

LOUPE top-level requirements

- All light of the Earth's disk should be collected
- Observations should cover all phase angles
- Observations should cover the Earth's daily rotation
- Observations should cover wavelengths from ~ 400 - 800 nm
- Total flux and polarized fluxes should be measured
- The spectral resolution should be ~ few nm (*F*) and ~20 nm (*P*)
- The spectrometric accuracy should be better than 0.5%
- The polarimetric accuracy should be ~1%
- The instrument should be small, robust & require little power

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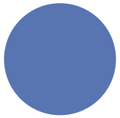
Artist's impression of ESA's Lunar Lander

Different options for LOUPE

LOUPE 1A

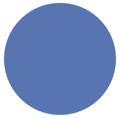


Total flux + linear polarization (Snik et al., 2009)
Spatially unresolved disk

LOUPE 1B

Total flux + linear polarization (Snik et al., 2009)
Spatially resolved disk

LOUPE 2A



Total flux + full polarization (Sparks et al., 2013)
Spatially unresolved disk

LOUPE 2B

Total flux + full polarization (Sparks et al., 2013)
Spatially resolved disk

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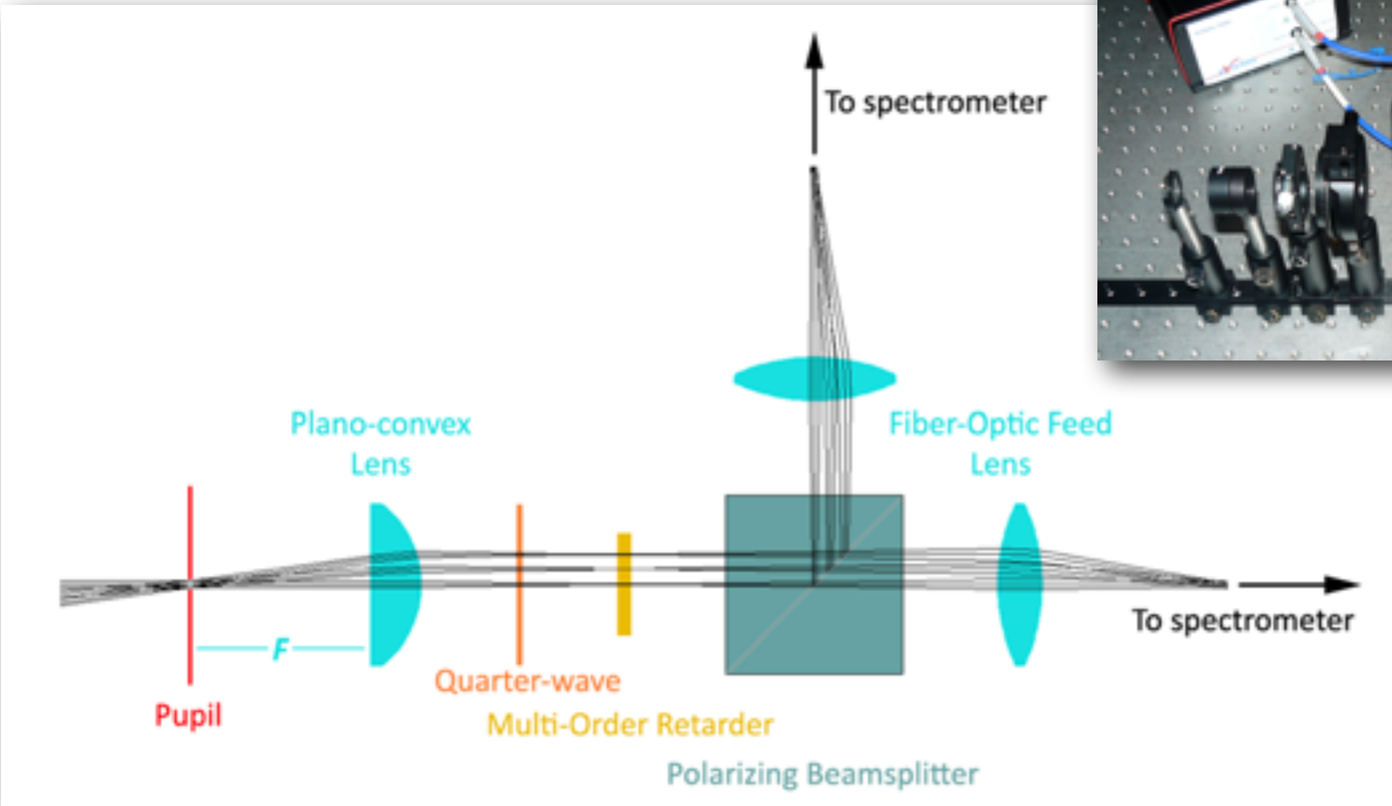
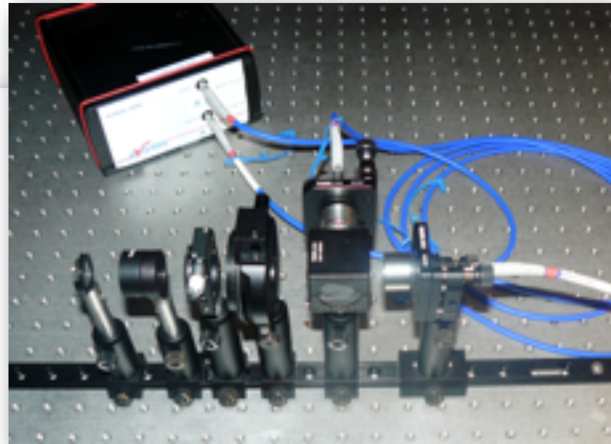


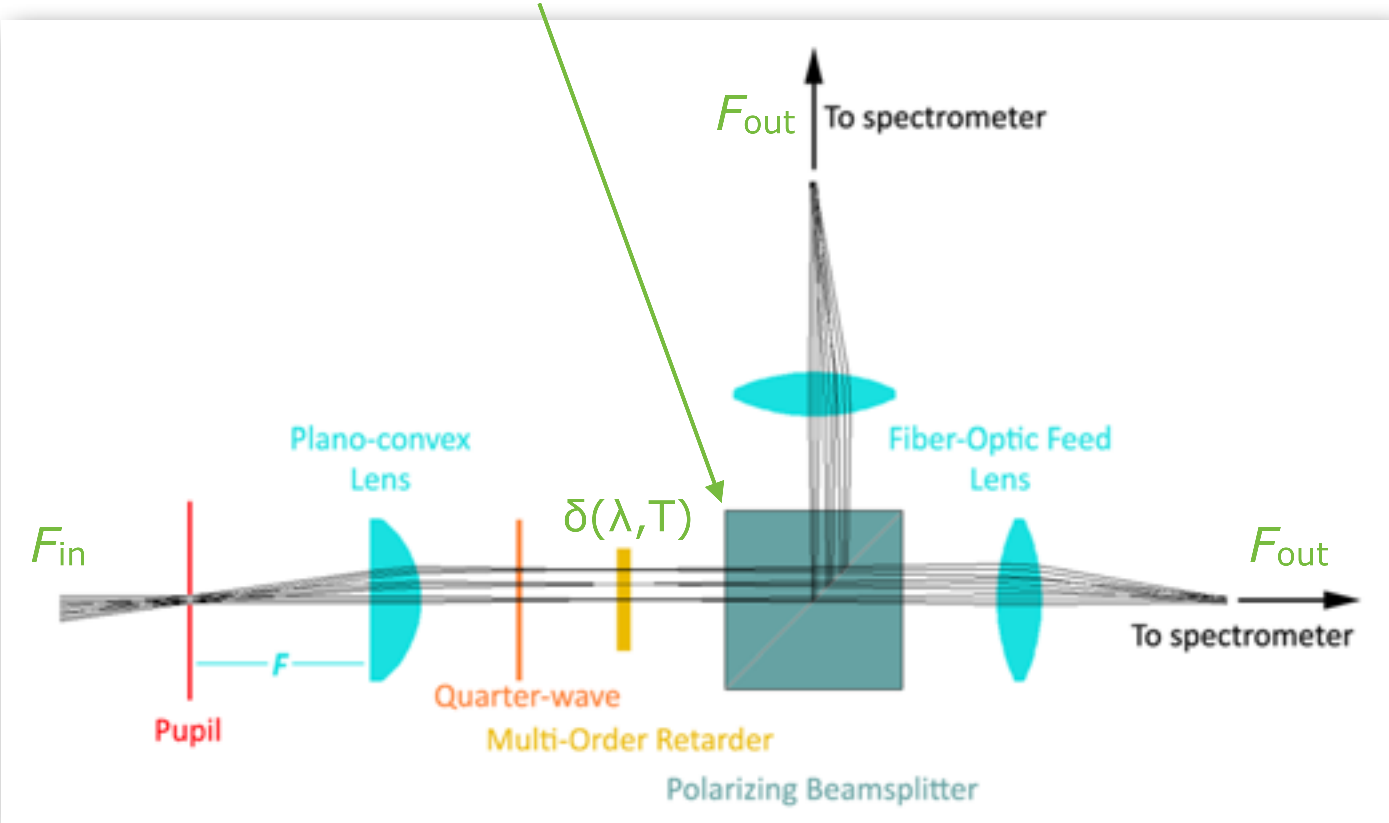


Credit: Jens Hoeijmakers [Leiden]

LOUPE's spectropolarimetric technique

This design uses the 'SPEX' spectral modulation method developed by Snik, Karalidi, & Keller (2009):

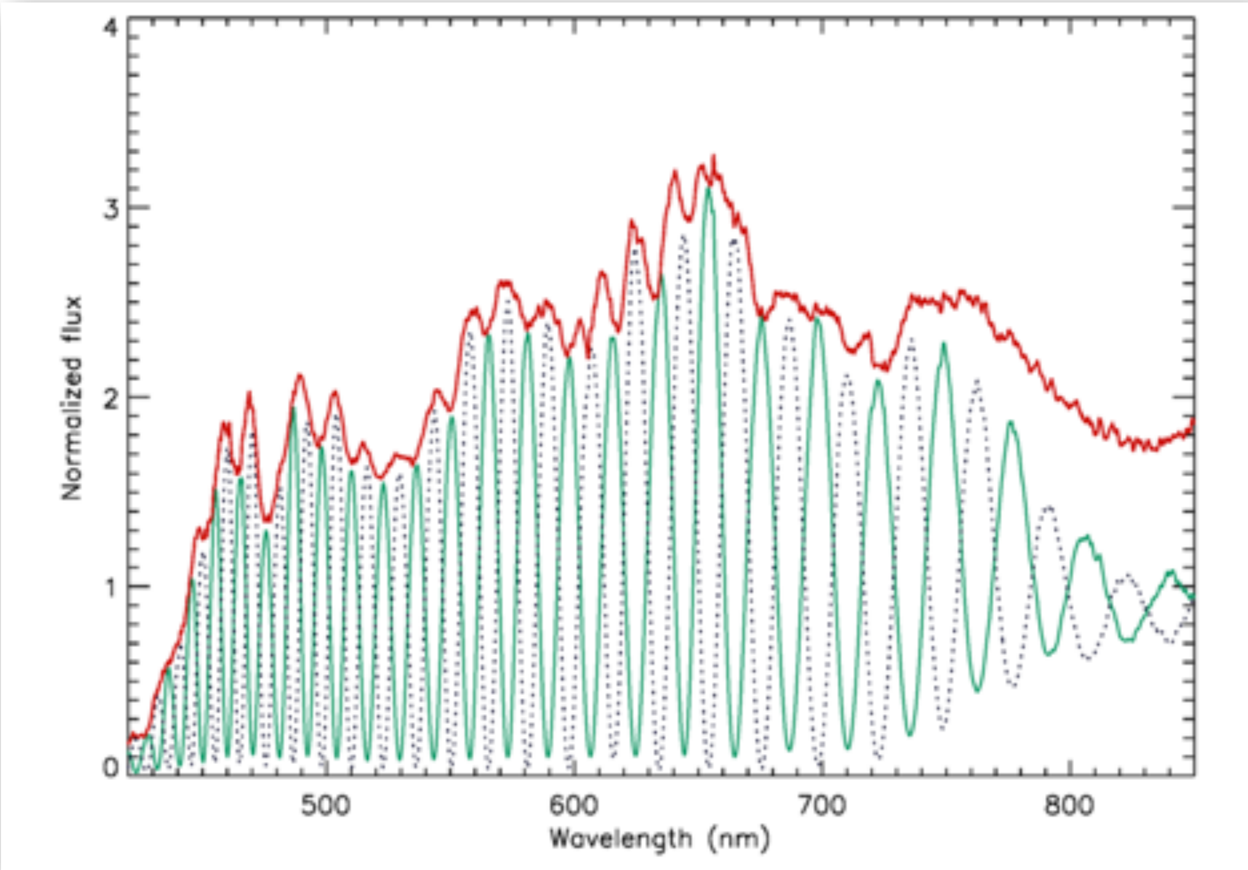
$$F_{out}(\lambda) = 0.5\ F_{in}(\lambda)\ [1 \pm P(\lambda) \cos(2\chi(\lambda) + 2\pi\delta/\lambda)]$$



Credit: Jens Hoeijmakers [Leiden]

Test measurements LOUPE 1A

First test measurements using a polarized source (light source + linear sheet polarization):



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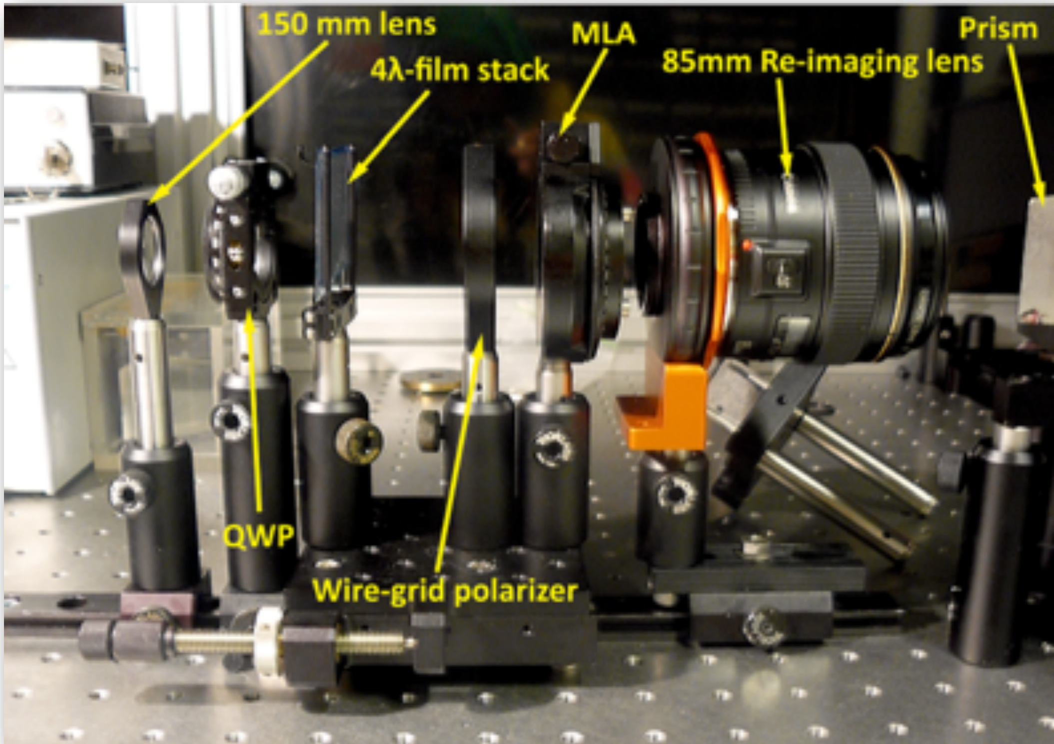
Different options for LOUPE

LOUPE 1B

Total flux + linear polarization (Snik et al., 2009)
Spatially resolved disk

MLA: Microlens Array



Credit: Jens Hoeijmakers [Leiden]

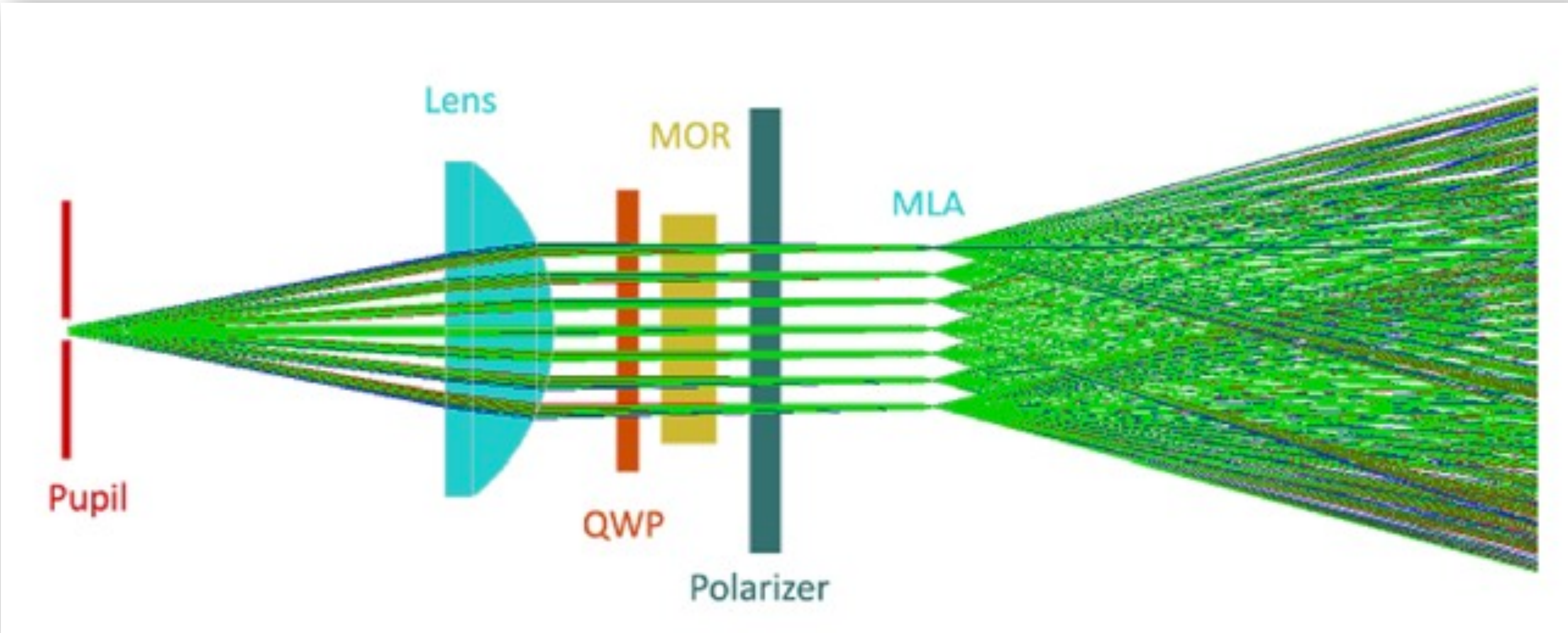
The model planet

Different options for LOUPE

LOUPE 1B

Total flux + linear polarization (Snik et al., 2009)
Spatially resolved disk

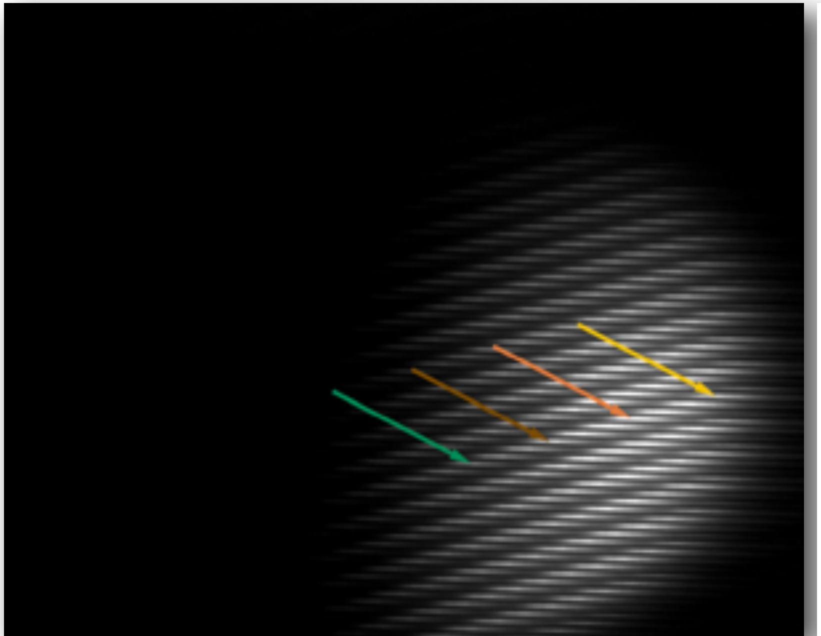
~ 100 pixels across the planet

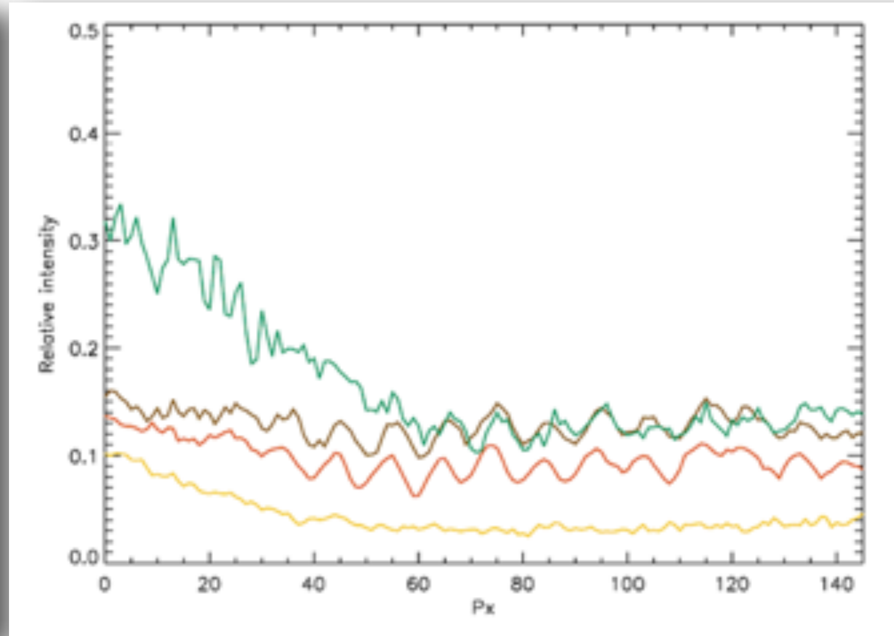


Credit: Jens Hoeijmakers [Leiden]

Test measurements LOUPE 1B

First test measurements of the styrophome planet:





Credit: Jens Hoeijmakers [Leiden]

Conclusions for LOUPE 1A & 1B

- Disk integration is achieved
- Spatial information can be retained
- The spectral range can be achieved
- The spectral resolution on the flux is achieved
- The spectral resolution on the polarization is achieved
- Size, mass should be achievable with custom optics
- Power budget is small (only the detector)

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- Polarimetric accuracy (styrophome sphere model?)

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Measurements with a SPEX-demonstration model have shown that the sensitivity for *P* is better than 0.001

Future lunar landers

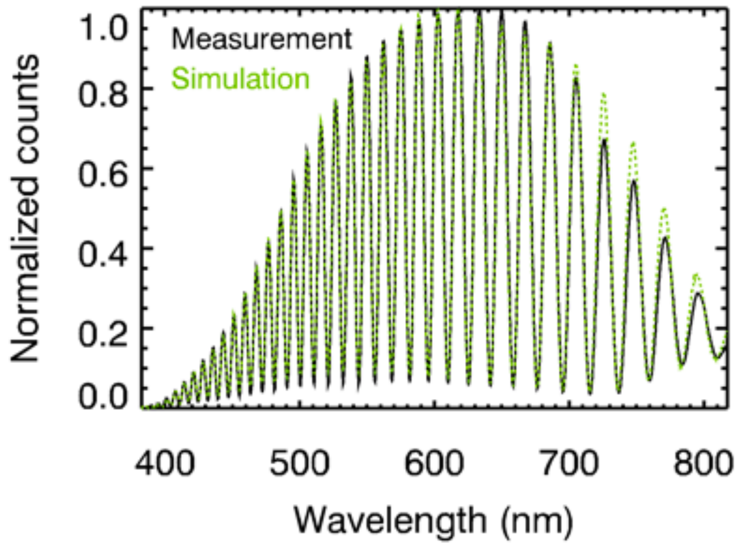
The perfect lunar lander for LOUPE:

- Lands on the Earth-side of the moon
- Has a power source lasting throug the lunar night
- Has an antenna that will be aimed at Earth

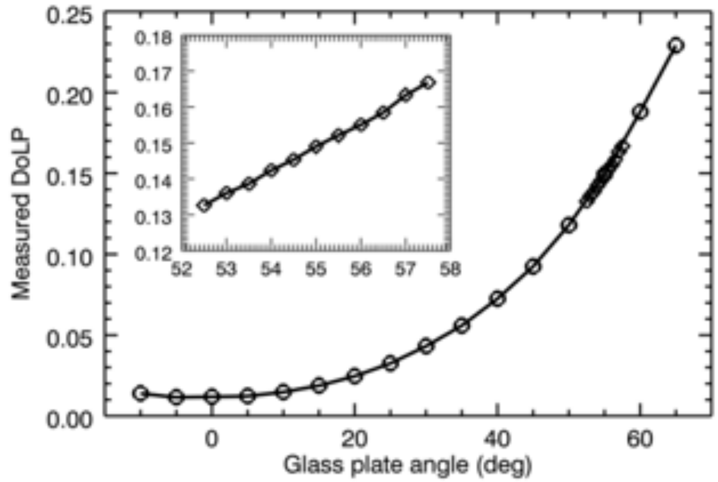
Artist's impression of ESA's Lunar Lander

SPEX demonstration model: accuracy

The SPEX demonstration model has been tested for accuracy, stray light, etc. The sensitivity for P is better than 0.001:



Test measurement of 1 aperture, with a 100% polarized white light source. The simulation is with SPEX instrument simulator software.



Test measurement for the sensitivity of the polarisation measurements using a rotating plane glass plate. At non-zero rotation angles, the beam entering the SPEX model is polarized. The figure shows measurements and the model fit.