# Experimental scattering matrices of lunar dust simulant at 488nm and 520nm.

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LETTER

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# Biosignatures as revealed by spectropolarimetry of Earthshine

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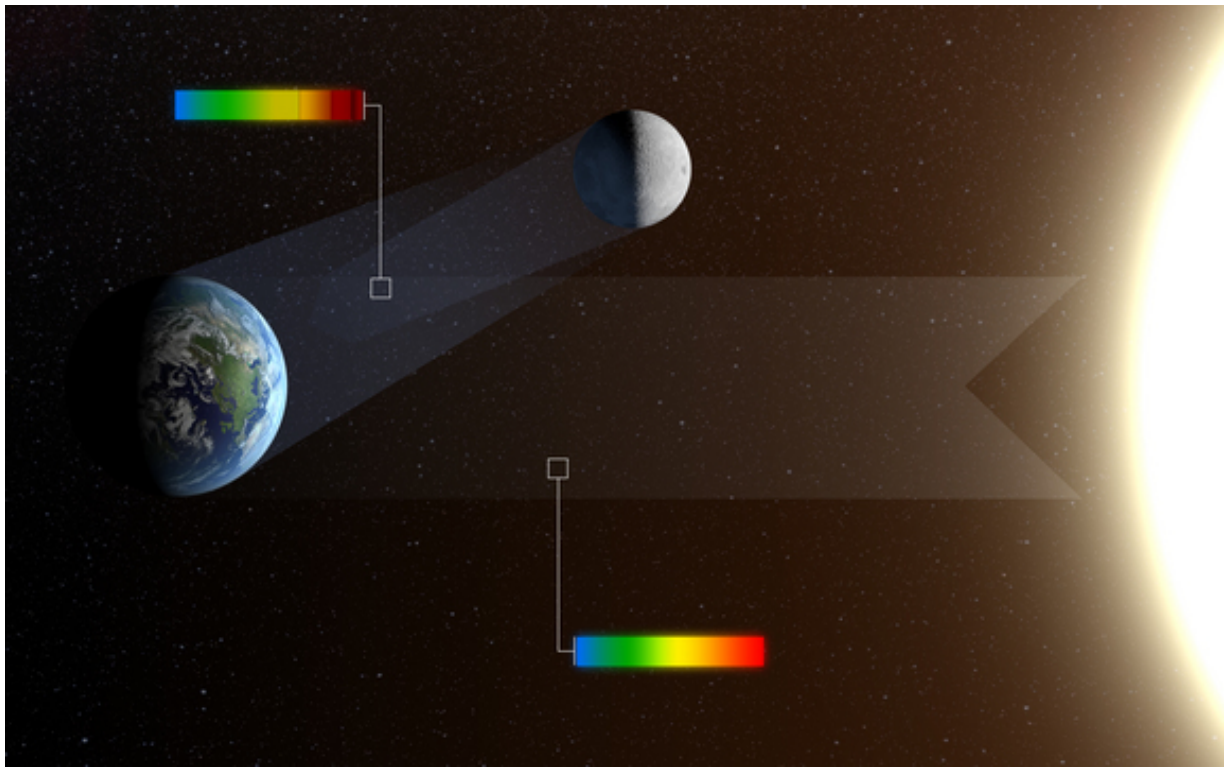
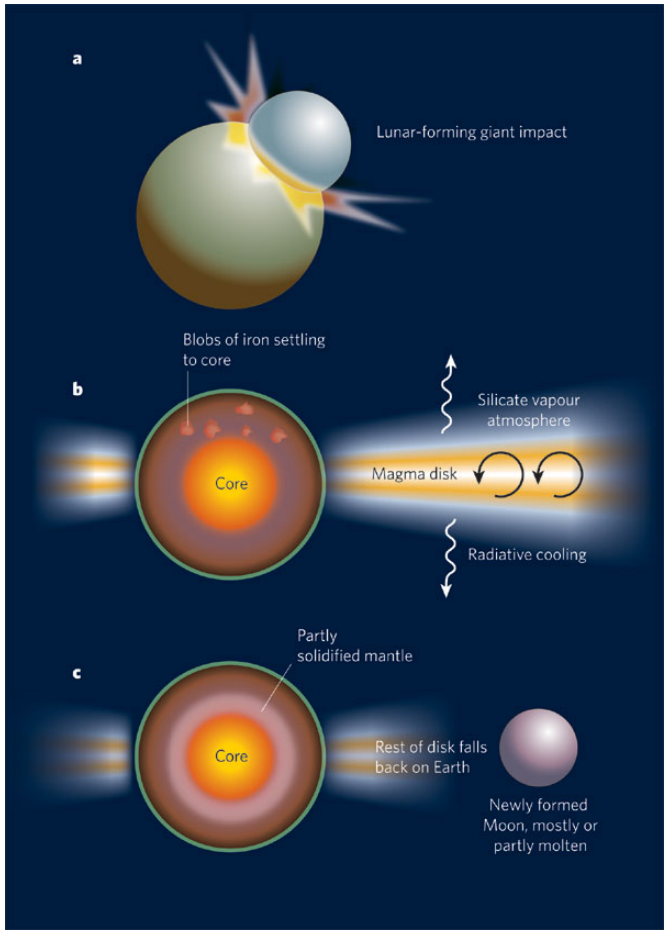
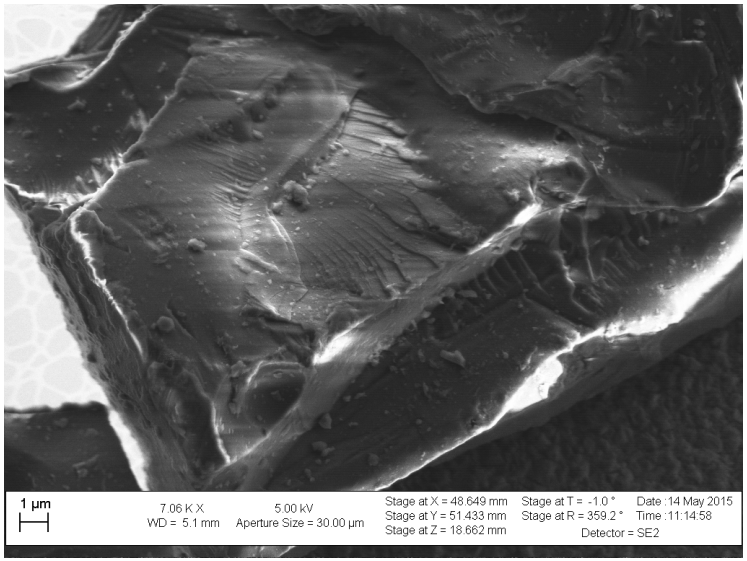


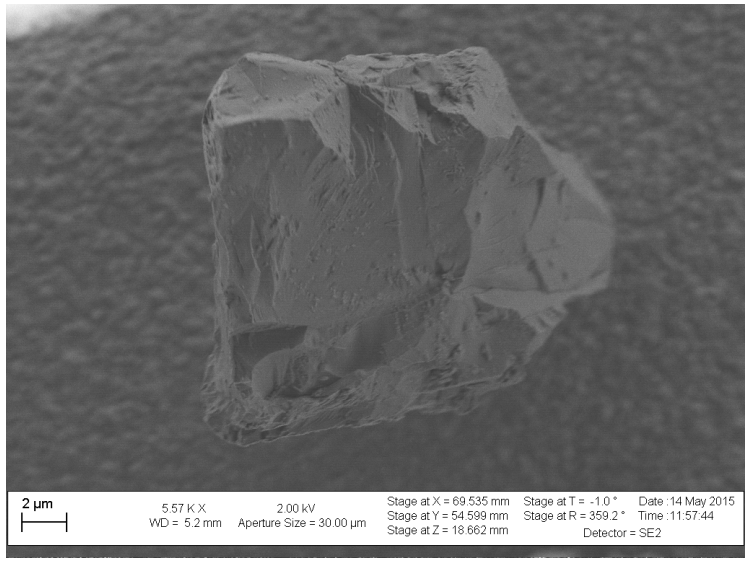


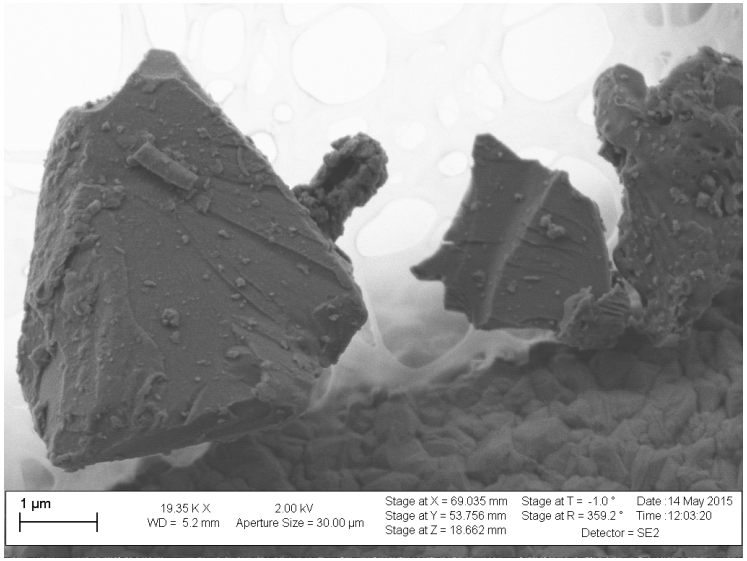

David J. Stevenson, Nature **451**, 261-265 (2008).

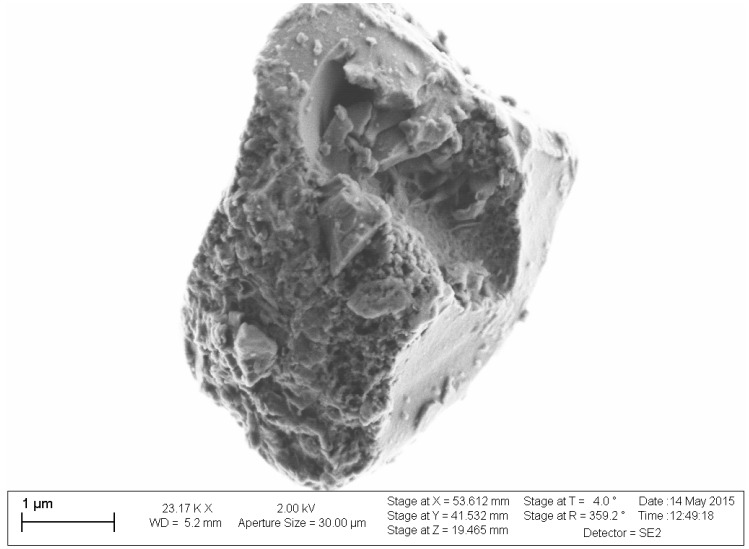
| | Apollo 17 sample 70051 | JSC-1A lunar simulant | Mars analog basalt |
|---|---|---|---|
| $SiO_3$ | 42.2 | 45.7 | 43.9 |
| $Al_2O_3$ | 15.7 | 16.2 | 8.4 |
| $CaO$ | 11.5 | 10.0 | 6.3 |
| $MgO$ | 10.3 | 8.7 | 7.0 |
| $FeO$ | 12.4 | - | - |
| $Fe_2O_3$ | - | 12.4 | 20.7 |
| $Na_2O$ | 0.2 | 3.2 | 2.1 |
| $K_2O$ | 0.1 | 0.8 | 0.7 |
| $TiO_2$ | 5.1 | 1.9 | 0.8 |
| $P_2O_5$ | - | 0.7 | 1.0 |
| $MnO$ | 0.2 | 0.2 | 0.4 |

- **Mare** regolith simulant (low-Ti).
- Composition: basaltic ashes. No chemical treatment performed.
- Physical treatment: milling and sieving to reproduce size distribution.
- Refractive index (in the visible): 1.65+0.003i (Goguen et al. (2010)).
- Size distribution: $r_{eff}$=17.68$\mu m$, $v_{eff}$=1.59


1 µm
7.06 K X
WD = 5.1 mm
5.00 kV
Aperture Size = 30.00 µm
Stage at X = 48.649 mm
Stage at Y = 51.433 mm
Stage at Z = 18.662 mm
Stage at T = -1.0 °
Stage at R = 359.2 °
Date :14 May 2015
Time :11:14:58
Detector = SE2

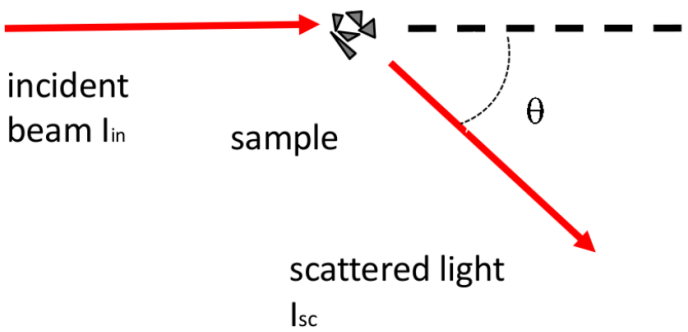

2 µm
5.57 K X
WD = 5.2 mm
2.00 kV
Aperture Size = 30.00 µm
Stage at X = 69.535 mm
Stage at Y = 54.599 mm
Stage at Z = 18.662 mm
Stage at T = -1.0 °
Stage at R = 359.2 °
Date :14 May 2015
Time :11:57:44
Detector = SE2


1 µm
19.35 K X
WD = 5.2 mm
2.00 kV
Aperture Size = 30.00 µm
Stage at X = 69.035 mm
Stage at Y = 53.756 mm
Stage at Z = 18.662 mm
Stage at T = -1.0 °
Stage at R = 359.2 °
Date :14 May 2015
Time :12:03:20
Detector = SE2


1 µm
23.17 K X
WD = 5.2 mm
2.00 kV
Aperture Size = 30.00 µm
Stage at X = 53.612 mm
Stage at Y = 41.532 mm
Stage at Z = 19.465 mm
Stage at T = 4.0 °
Stage at R = 359.2 °
Date :14 May 2015
Time :12:49:18
Detector = SE2

## Scattering Matrix

$$\begin{pmatrix} I_{sc} \\ Q_{sc} \\ U_{sc} \\ V_{sc} \end{pmatrix} = \frac{\lambda^2}{4\pi^2 D^2} \begin{pmatrix} F_{11} & F_{12} & F_{13} & F_{14} \\ F_{21} & F_{22} & F_{23} & F_{24} \\ F_{31} & F_{32} & F_{33} & F_{34} \\ F_{41} & F_{42} & F_{43} & F_{44} \end{pmatrix} \begin{pmatrix} I_{in} \\ Q_{in} \\ U_{in} \\ V_{in} \end{pmatrix}$$

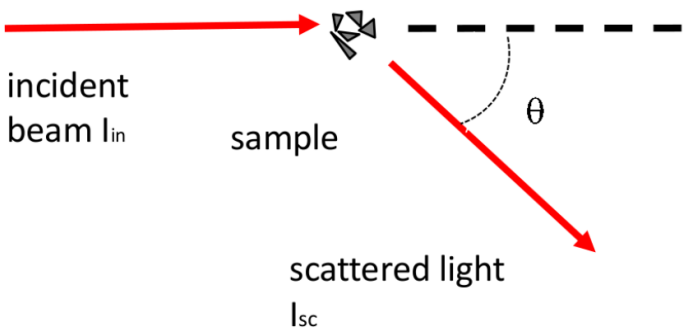



Scattering matrix depends on:

- Scattering angle
- Refractive index
- Size distribution
- Shape
- Orientation
- Wavelenght

## Scattering Matrix

$$\begin{pmatrix} I_{sc} \\ Q_{sc} \\ U_{sc} \\ V_{sc} \end{pmatrix} = \frac{\lambda^2}{4\pi^2 D^2} \begin{pmatrix} F_{11} & F_{12} & 0 & 0 \\ F_{12} & F_{22} & 0 & 0 \\ 0 & 0 & F_{33} & F_{34} \\ 0 & 0 & -F_{34} & F_{44} \end{pmatrix} \begin{pmatrix} I_{in} \\ Q_{in} \\ U_{in} \\ V_{in} \end{pmatrix}$$

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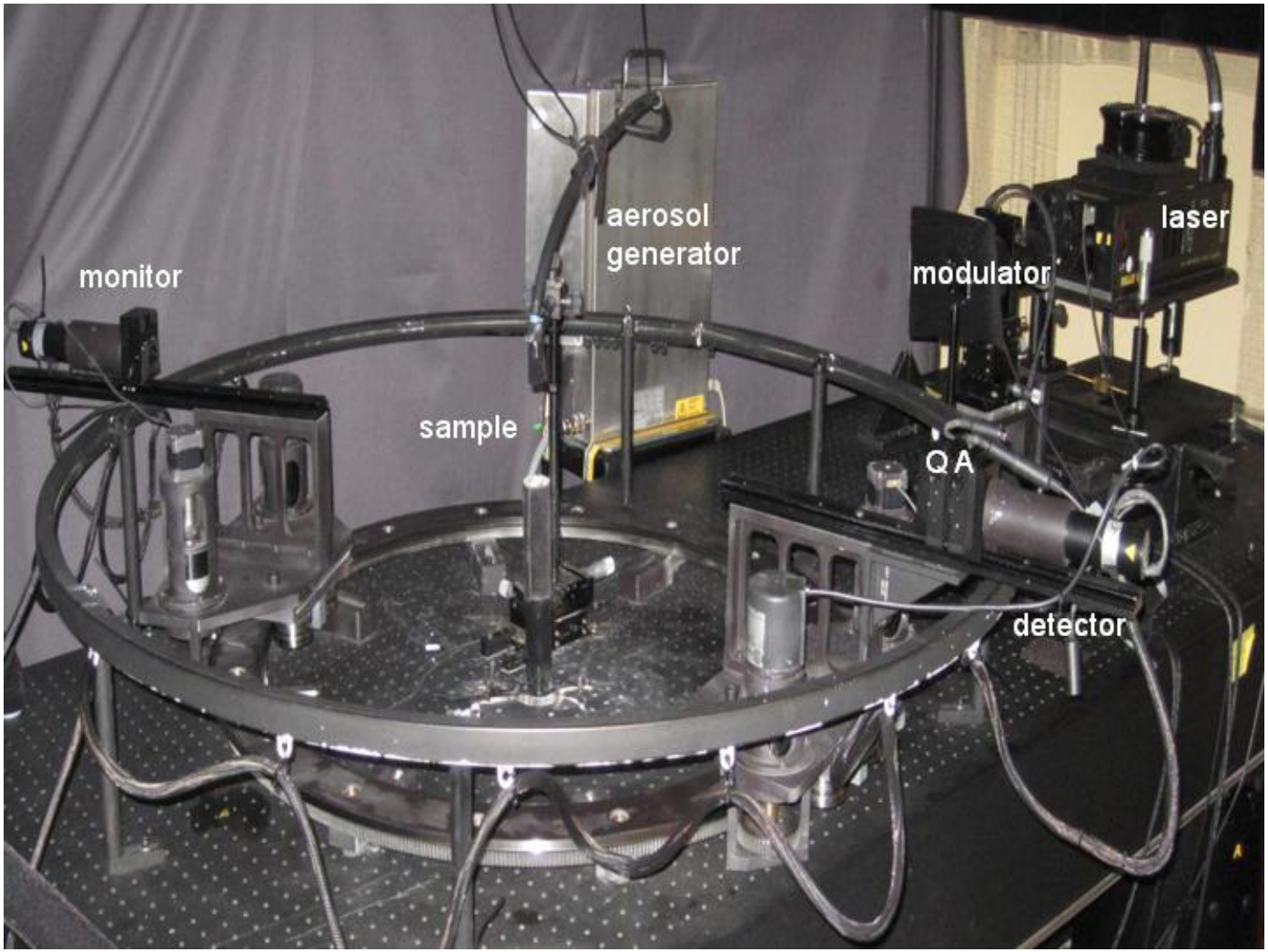
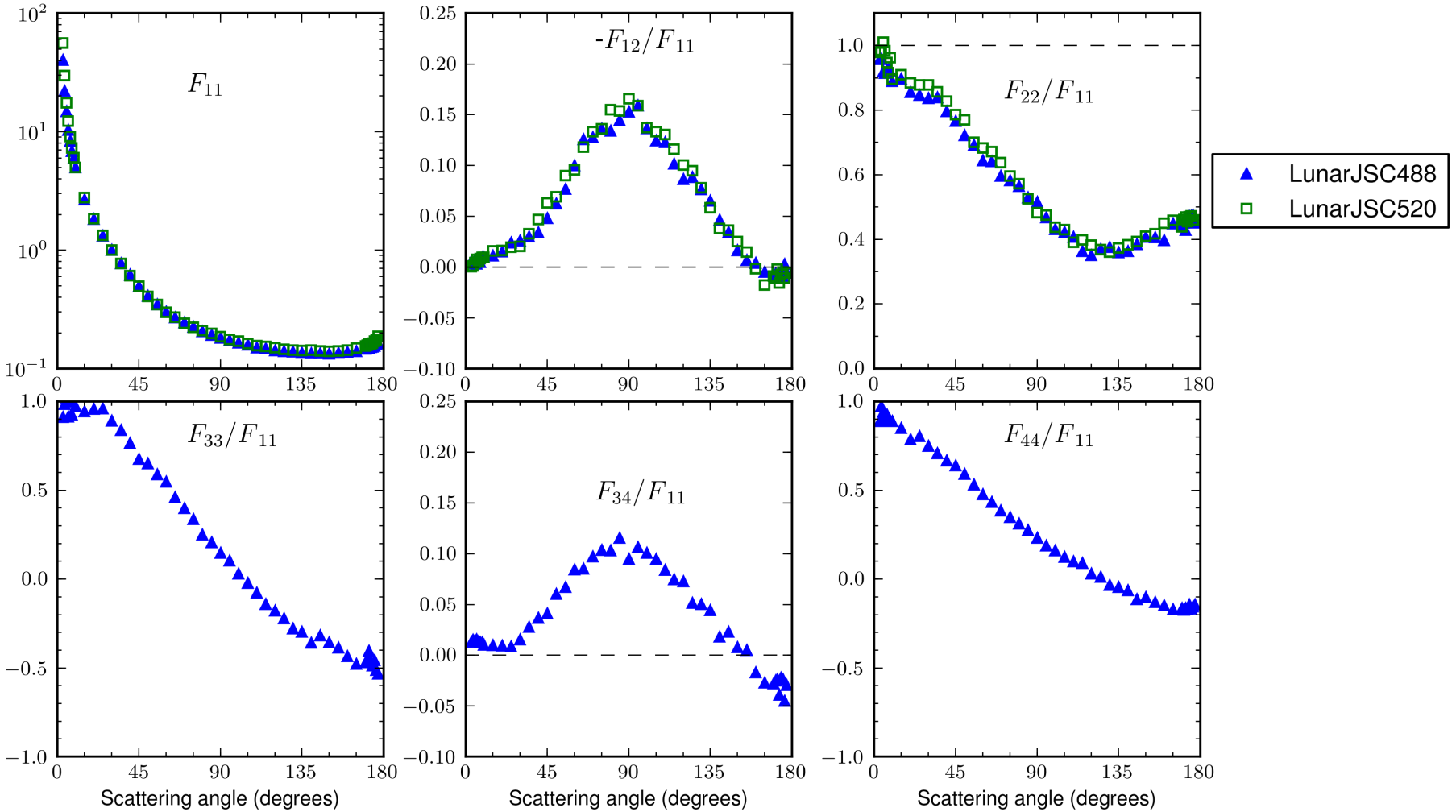
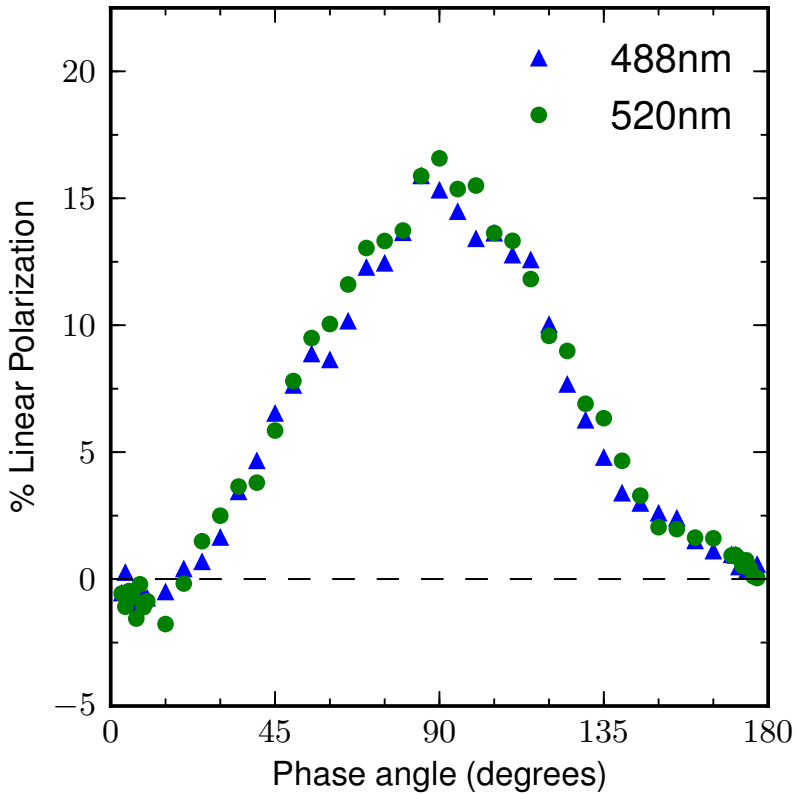
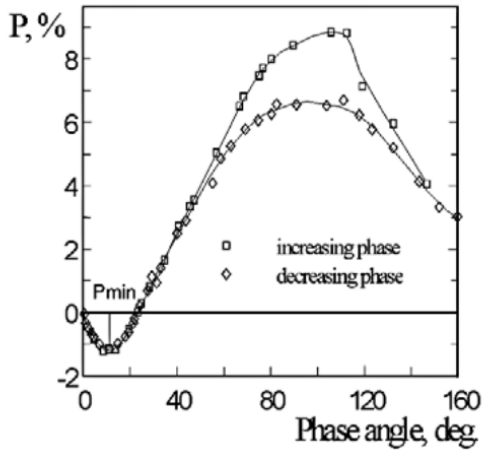



Cosmic Dust Laboratoy (CoDULab) at IAA.

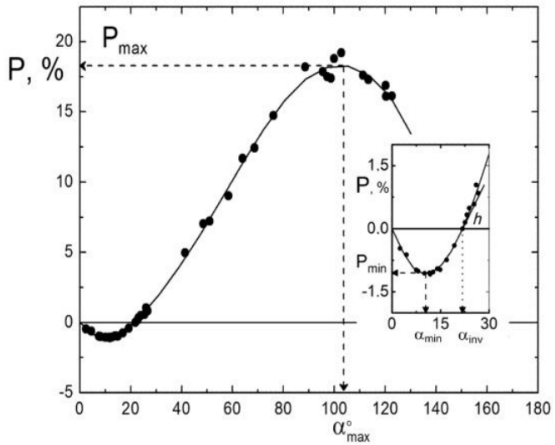

$F_{11}$
$-F_{12}/F_{11}$
$F_{22}/F_{11}$
$F_{33}/F_{11}$
$F_{34}/F_{11}$
$F_{44}/F_{11}$
LunarJSC488
LunarJSC520
Scattering angle (degrees)
Scattering angle (degrees)
Scattering angle (degrees)



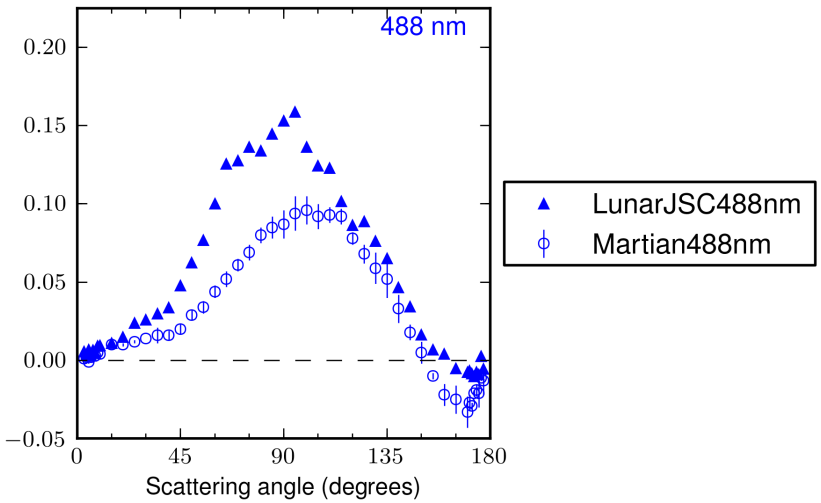

| | $P_{max}$ | $\alpha_{max}$ | $P_{min}$ | $\alpha_{min}$ | Inversion angle |
|---|---|---|---|---|---|
| $\mu m$ Lyot | 6.5-9 % | 100° | 1.3 % | 10° | 22° |
| Kvaratskhelia | 18 % | 104° | 1 % | 10° | 22° |
| Our measurements | 16.5 % | 90° | 1 % | 10° | 22° |

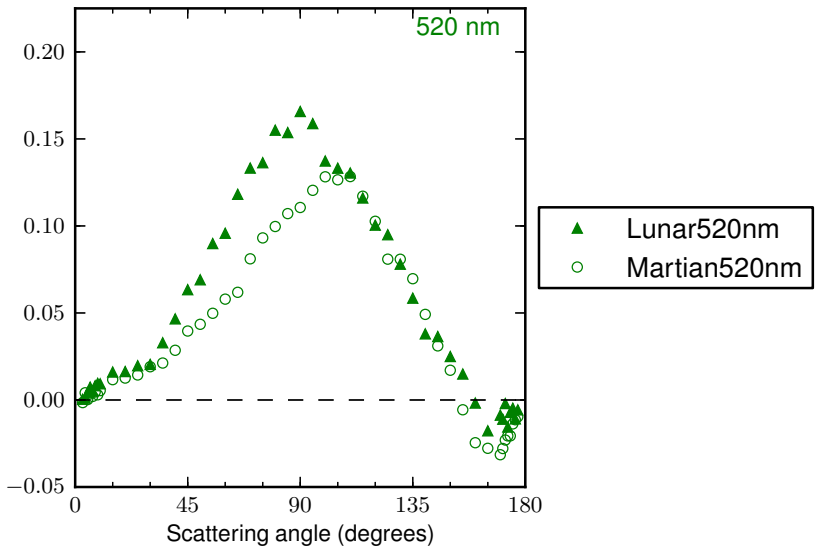


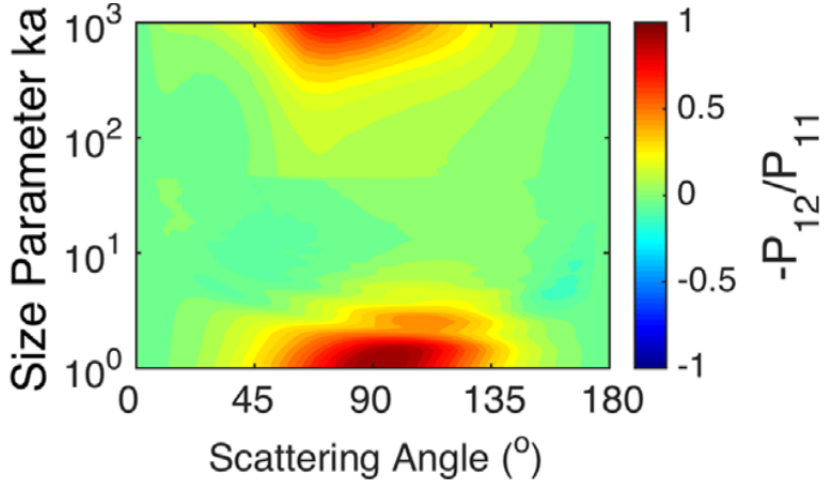

Lyot (1929).




Kvaratskhelia et al. (1988) (430nm).



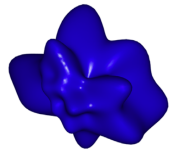




Liu et al.(2015).

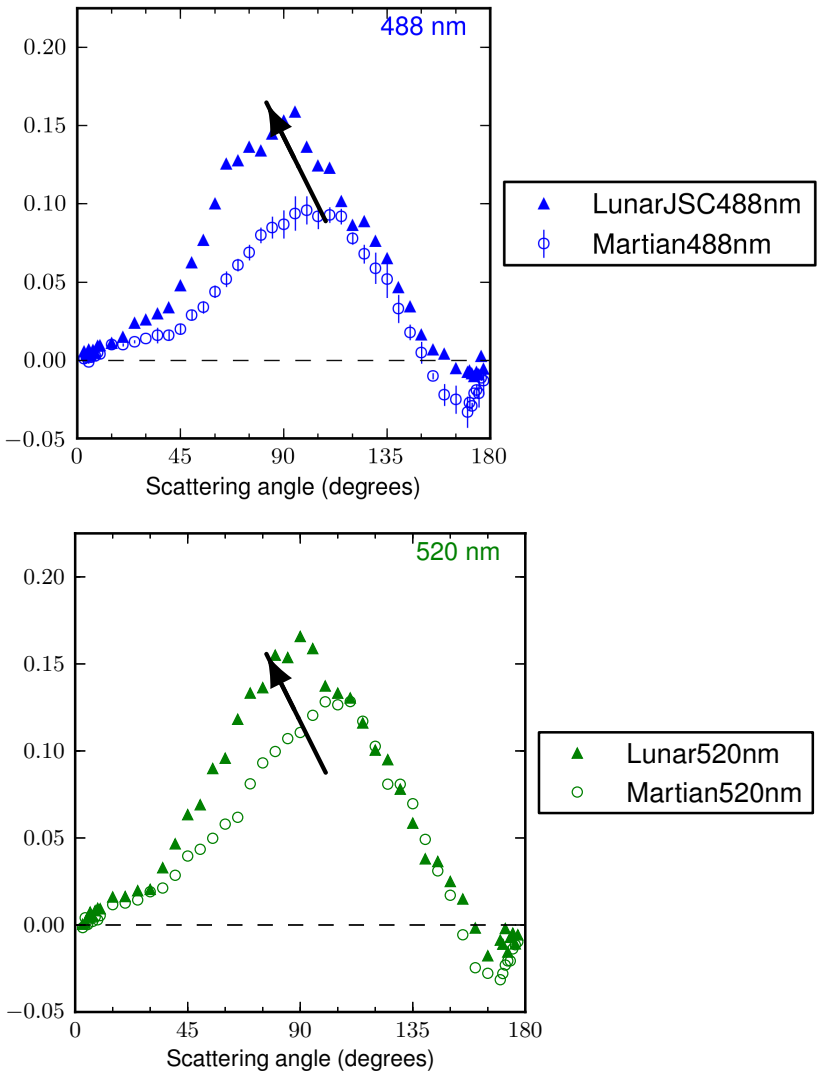
$$x = \frac{2\pi r}{\lambda}$$

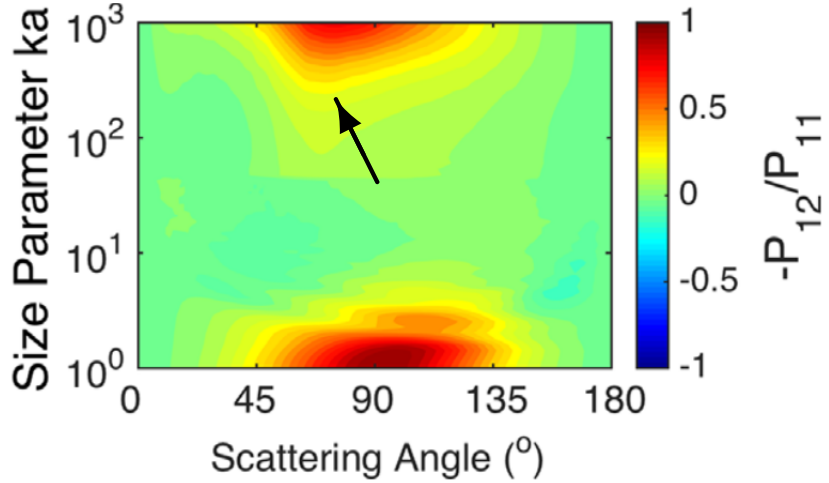
Size parameter formula



n=1.5+0.001i

| | LunarJSC | Martian analog |
|---|---|---|
| Refraction index(visible range) | 1.65+0.003i | 1.52+0.00092i |
| Size distribution(Mie) | $r_{eff}$=17.68$\mu m$ ; $v_{eff}$=1.59 | $r_{eff}$=6.9$\mu m$ ; $v_{eff}$=7 |
| Effective size parameter(488nm) | 227 | 88 |
| Effective size parameter(520nm) | 213 | 83 |

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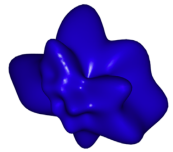

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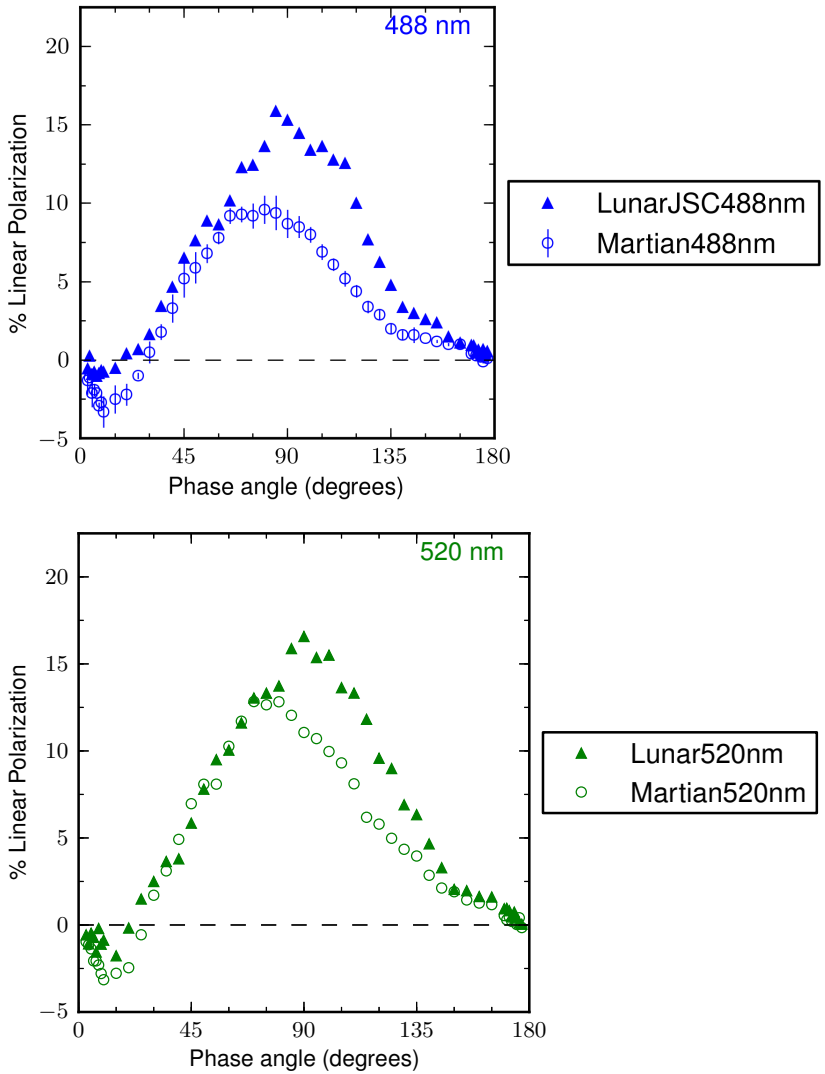


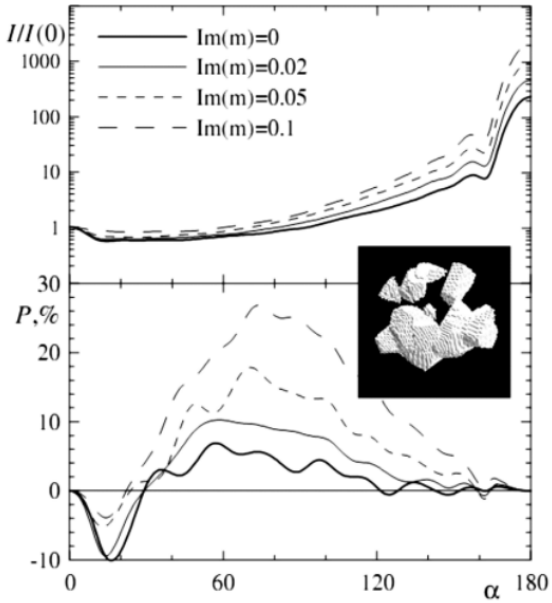


Zubko et al.(2005)

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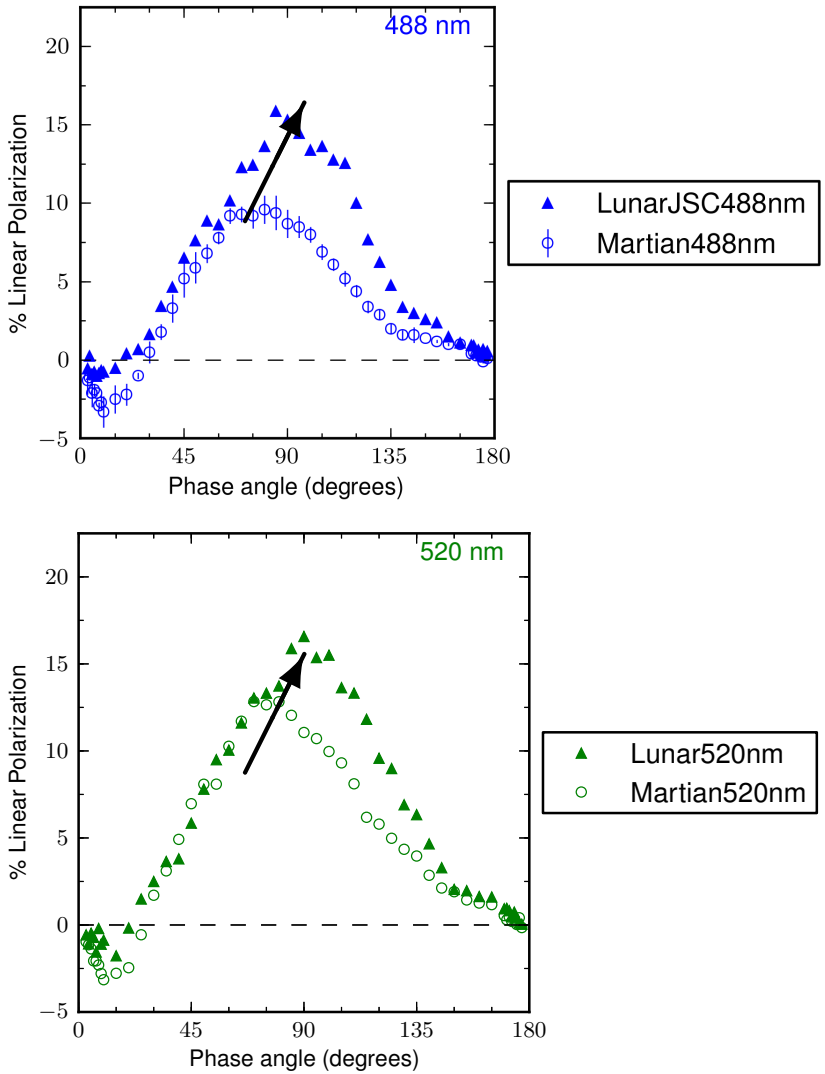


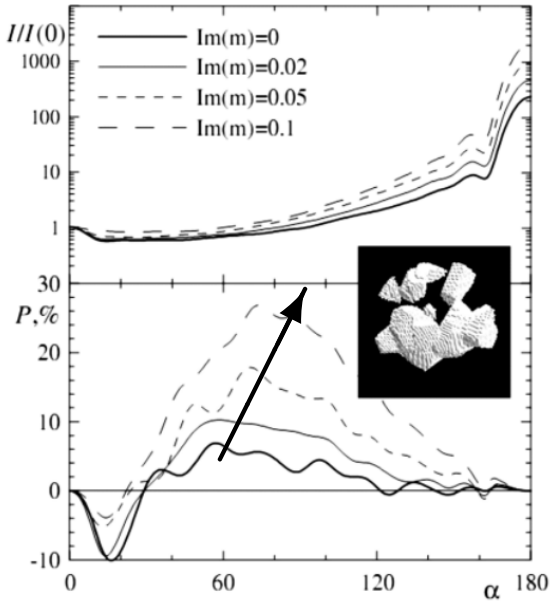


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- Measurements for 633nm.
- Calculations with irregular particles.
- Measurements with high-Ti sample to fully characterize Moon surface.