1686: JUPITER'S SATELLITE EUROPA: POLARIZATION PROPERTIES EXPLAINED BY A SUB-MICRON, HIGHLY POROUS REGOLITH

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Introduction

It has been known for more than a century that the intensity and the polarization state of sunlight reflected from solar system objects varies depending on the phase angle, θ (angle made by sun-object-observer geometry), at the time of the observation. Polarization measurements have been made in the laboratory to understand the nature of clouds, aerosols, planetary ring systems and planetary regolith materials. The Polarization Phase Curve (PPC) and Reflectance Phase Curve (RPC) have been reported for almost all solar system objects. RPCs and PPCs have also been measured in the laboratory with goniometric photopolarimeter (GPP) observations of returned lunar samples and particulate materials. [1-8]

The Instrument

We have reconfigured a goniometric photopolarimeter (GPP) [7] to measure the RPC and PPC of highly reflective particulate materials that might simulate Europa's predominately water ice regolith. We apply the Reciprocity Principle (HRP) formulated by Helmholtz in 1856 by presenting our samples with linearly polarized light and measuring the change in the intensity of the reflected component at angles from 0.05 <θ< 15°. Assuming the particles are randomly oriented, this is physically equivalent to astronomical polarization measurements [9,10]. We report here the RPC and PPC for a suite of high albedo particulates of size fractions from 0.1<D< 30 μm, five of which are 1.5 μm or smaller in diameter.

The depth and position of the polarization minimum, the crossover point, and the slope at the crossover point all correlate with particle size and packing density of the candidate regolith material. Our results suggest that Europa's regolith may have high void space-perhaps exceeding 90%! This has importance in the design of proposed Europa surface instruments on future missions.

The Experiment

We measured the RPC and PPC of 13 well-sorted particle size fractions of Aluminum Oxide (Al_2O_3) industrial optical abrasives with diameters 0.1 ≤ D ≤ 30 μm. The Al_2O_3 powders are supplied by the manufacturer in size fractions that are larger than, comparable to, and smaller than the wavelength of our monochromatic incident light (λ=0.635μm). These materials are excellent planetary regolith analogues for solar system objects of high geometric albedo such as Io, Europa, and Ganymede. If the HRP applies, the RPCs and PPCs from this work should agree with those of the same materials that we reported previously, where the polarization of the reflected component was analyzed.

The samples were gently poured into sample cups and lightly shaken to allow for settling so as the surface might best replicate a powdered regolith on a planetary surface. The samples had very high void space as calculated from the mass of the powder in the cup compared to the volume of the cup. The finest particle sizes had the highest void space, exceeding 90%. (See companion abstract #1695 , this meeting). We compare the RPCs and PPCs from our earlier work [7,8] with those obtained for the same materials measured in a HRP configuration used in this experiment. The phase angle in the earlier work was 0<θ<5°.

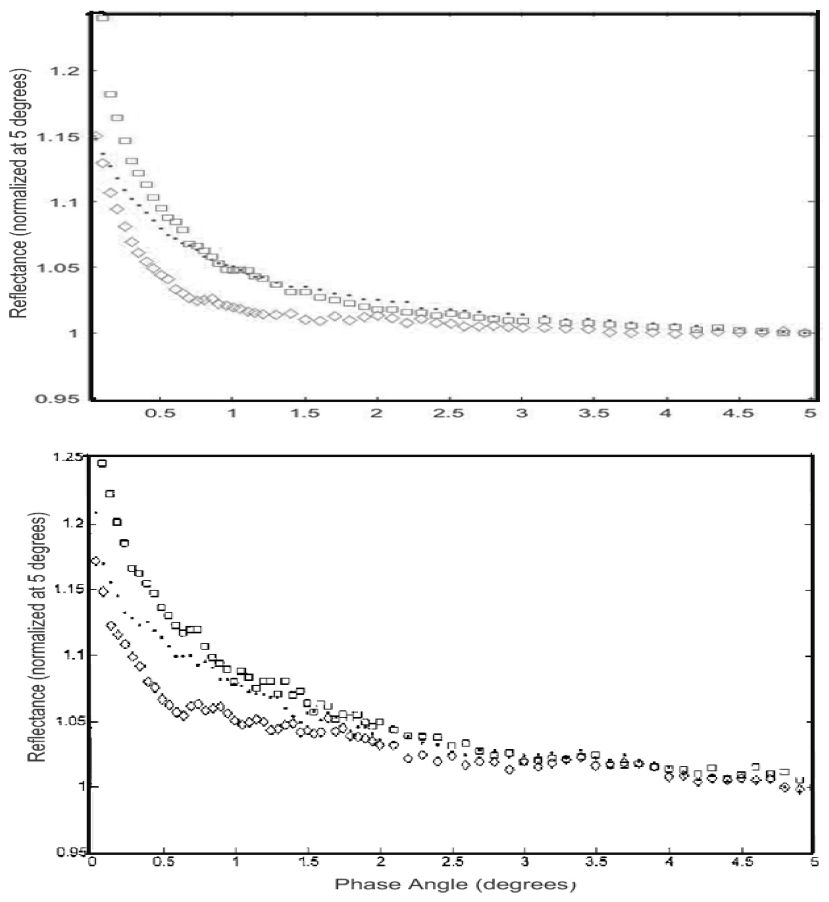

Fig. 1. Top. RPCs from this study for three particle sizes of Al_2O_3. Diamonds – 30 μm, Squares – 1.0 μm, Dots- 0.1 μm. Bottom. Same as above except from [7]. These three reflectance measurements are consistent with the HRP.

Reflectance Phase Curves

Reflectance phase curves for three particle size fractions are shown in Fig. 1 top. (0.1 μm data are plotted as dots, 1.0 μm as squares, and 30.09 μm as diamonds). These particle sizes were selected because they are smaller than, approximately equal to and larger than the wavelength of the incident radiation. For comparison, Fig 1 (bottom) shows the RPCs of the same three materials measured in our earlier work in which we placed linear and circular polarizers in the path of the reflected light before it entered the detector. Fig 1 demonstrates that the reflectance phase curves we report are consistent with what would be expected assuming the HRP applies.

Our reconfigured instrument expands the phase angle range to 15°. We find that in this phase angle range the empirical function y=a.exp(-bθ) +c.exp(-dθ) can be easily fitted to the entire range of particle sizes. We show a typical fit in Figure 2. These data, near small phase angle, are useful to remote sensing observers of outer solar system objects which can only be observed at small phase angle.

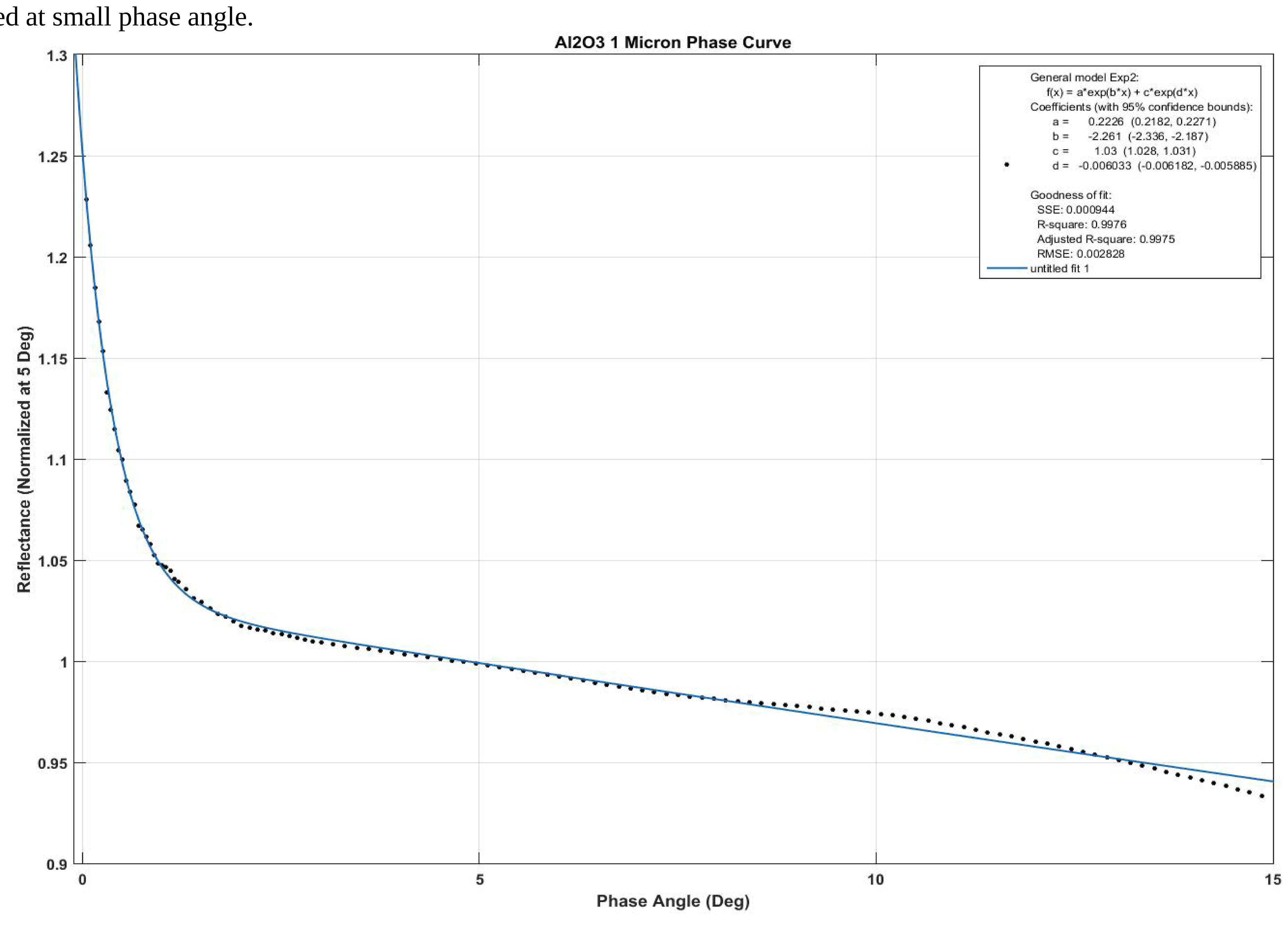

Fig. 2. Reflectance Phase Curve of 1.0 μm Al_2O_3 particles . The expression y=a·exp(-bθ) +c·exp(-dθ) has been fitted to the data.

Polarization Phase Curves

Polarization phase curves for Al_2O_3 particles of size 0.1, 0.5 and 1.0 μm are shown in Fig 3 (top) . These measurements were made by presenting the sample with linearly polarized light and measuring the intensity of the reflected component. In 2002, we measured the PPCs of these same Al_2O_3 materials using a GPP at the Karazin University in Kharkiv, Ukraine [8]. The Karazin University instrument presents the sample with non-polarized light and analyzes the polarization of the reflected component. The Karazin University GPP had been previously calibrated to the JPL GPP and the reflectance results from both instruments were consistent when measuring like materials. The Karazin GPP results are reproduced in Fig 3 (bottom). Fig 3 shows that for particle sizes that are larger than, comparable to and smaller than the wavelength of the incident radiation, the PPCs are alike. This is consistent with the results expected assuming the HRP applies.

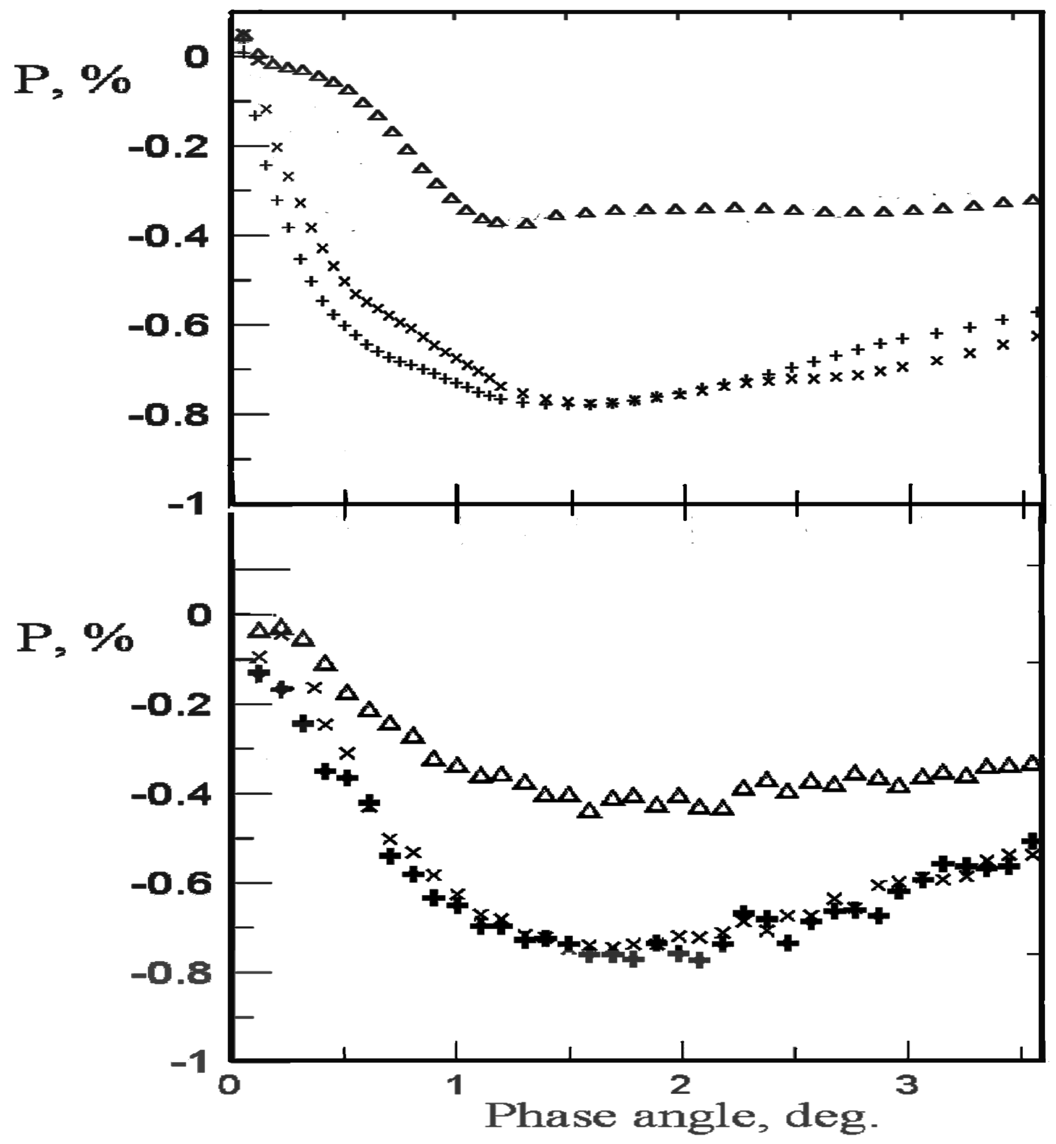

Fig. 3. Top: PPCs for three particle sizes of Al_2O_3 from this study in which the samples were presented with polarized light and the intensity of the reflected component was measured. Triangles indicate 1.0 μm, crosses indicate 0.5 μm, and pluses indicate 0.1 μm.

Bottom: PPCs of the same materials when presented with non-polarized light and the polarization of the reflected component was measured. The absence of a significant difference in these phase curves is consistent with what would be expected based on the Helmholtz reciprocity principle.

Conclusion #1

We conclude that the similarity of the RPCs and the PPCs of the same materials reported here and the previous measurements of the RPCs reported from the GPP at JPL and the PPCs reported by the GPP at Karazin Institute are consistent with what would be expected assuming the Helmholtz reciprocity principle applies. To our knowledge this is the first experimental demonstration of the Helmholtz reciprocity principle using polarized and non-polarized light.

Understanding Europa's Regolith

In 1997 Rosenbush et al. [11], found a PPC of Europa that was unlike those reported for many other solar system objects. In subsequent reports they found that Europa, Ganymede and Io, the high albedo Galilean satellites, all have PPCs that have a pronounced asymmetric minimum at about 0.5°. Fig. 3 shows our polarization results for Al_2O_3 particles which simulate the particulate water ice particles on the surface of Europa. We are able to replicate the polarization phase curve of Europa using extremely fine grained and highly porous materials with void space exceeding 90%.

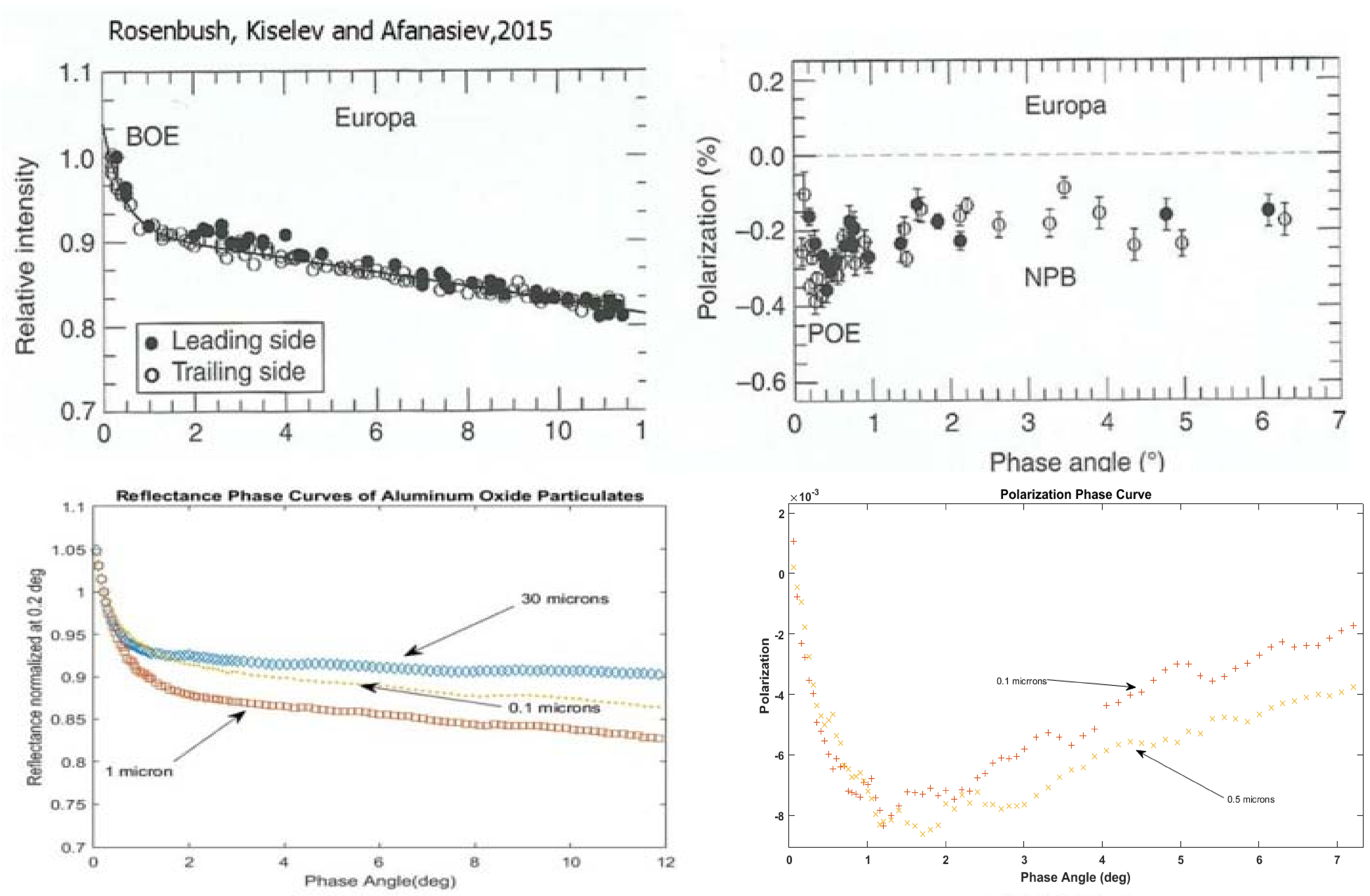

Fig. 4. Top: Rosenbush et al. [11] RPC and PPC for Europa.
Bottom: RPC and PPC of Al_2O_3 samples measured in this study. Europa's RPC can be explained due to a fine-grained regolith of extremely high void space.

Conclusion #2

The reflectance and polarization properties of Europa's regolith can be replicated in the laboratory by particulate assemblages that are fine grained and extremely porous. The understanding of Europa's surface texture (and hence internal thermal properties) will be improved dramatically by a combination and polarization and reflectance measurements from remote sensing missions such as Europa Clipper.

References

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