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Coherent Backscatter Opposition Effect from Saturn Ring Particles and Their Regoliths

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Abstract. The photometric phase curves of Saturn's A and B rings exhibit a sharp peak in reflectance when the phase angle approaches zero, commonly known as the opposition effect. Recent work has suggested that the width and amplitude of the opposition effect may be consistent with coherent backscattering from wavelength-sized grains which cover the surfaces of macroscopic ring particles.

1. Introduction

Much can be learned about the nature of Saturn's ring particles and their regoliths by studying their reflectance as a function of wavelength and phase angle. Photometric theory predicts specific behavior of the phase curves depending on regolith texture (Hapke, 1993).

One such behavior is the opposition effect, a sharp increase in the reflectance of an object's surface as the phase angle (the angular separation between the observer and the sun as seen from the target) approaches zero. The phase curves of Saturn's A and B rings demonstrate the opposition effect, exhibiting a sharp peak in ring brightness with decreasing phase angle (Franklin and Cook, 1965). The phase curves for Saturn's rings in B (Blue, effective wavelength of 0.4480 μm) and V (Visual, effective wavelength of 0.5540 μm) exhibit a wavelength dependence. Both the width and amplitude of the opposition effect as a function of wavelength provide information on ring particle size.

When the particles are larger than the wavelength of light, one source of the opposition effect results from the elimination of mutual shadows, or *shadow hiding*, between particles. The ring particles demonstrate increased reflectivity near 0^0 phase angle because at that phase angle each particle covers its own shadow. When the phase angle is slightly greater, the shadows of the foreground particles encroach upon particles in the background, decreasing the ring reflectivity.

Recently a different mechanism, *coherent backscatter*, has been used to explain the opposition effect (Hapke, 1990). Coherent backscatter occurs when the particles are on the order of or smaller than the wavelength of light and are separated by distances on the order of the wavelength of light. Light rays that travel the same path in opposite directions through a multiply-scattering medium combine coherently to produce a peak centered at 0^0 phase.

These two processes predict markedly different behaviors in the circular polarization ratio, μ_c, at small phase angles and can be tested in the laboratory. The circular polarization ratio is defined as the ratio of the intensity of light scattered with polarization in the same sense as the incident light to the intensity with polarization in the opposite sense. The shadow hiding process produces a peak that is strongly polarized in the opposite sense of the incident light and μ_c decreases with decreasing phase angle. The coherent backscatter process produces a peak that results from an enhancement of light scattered with polarization in the same sense as the incident light. The value of μ_c increases with decreasing phase angle and may become greater than 1.

2. Experiment Description

The instrument used to make these measurements was the short arm (1 m) goniometer in the Earth and Space Sciences Division of JPL. The sample is presented with opposite senses of circularly polarized light and orthogonal senses of linearly polarized light. The detector can measure both senses of circular and linear polarization of the reflected radiation over phase angles from 0.2^0 to 70^0.

The incident laser light (0.633 μm) is circularly polarized using quarter wave plates to produce right or left-handed circular polarization. At the detector a set of removable quarter wave plates permit measurement of the backscattered light in both senses of polarization. Linear polarizers repeat this process for orthogonal senses of linearly polarized light. Eight separate phase curves were measured for each sample (Nelson *et al.*, 1993). Particles sizes ranged from 0.1 μm to 100 μm. The samples were not sifted or compacted. Their top surfaces were flattened with a spatula. Further details of the experiment are given in (Nelson *et al.*, 1995).

3. Results

The reflectance of eight powders of mixed particle size was determined by summing the measurements of all eight phase curves listed in the Experiment Description section. Figure 1a shows the phase curves for each sample. The albedos of the powders range from a very bright powder, MgO, with a single scattering albedo of > 0.99 to a dark powder, CO_2O_3, with a single scattering albedo of 0.13. All samples exhibit an opposition effect with the brightest samples displaying the largest opposition peaks.

Next, the circular polarization ratios are plotted as a function of phase angle (see Figure 1b). The increase in circular polarization ratio with decreasing phase angle is evident for all samples, even in the dark samples. This increase in circular polarization ratio is consistent with the results expected for the coherent backscattering process.

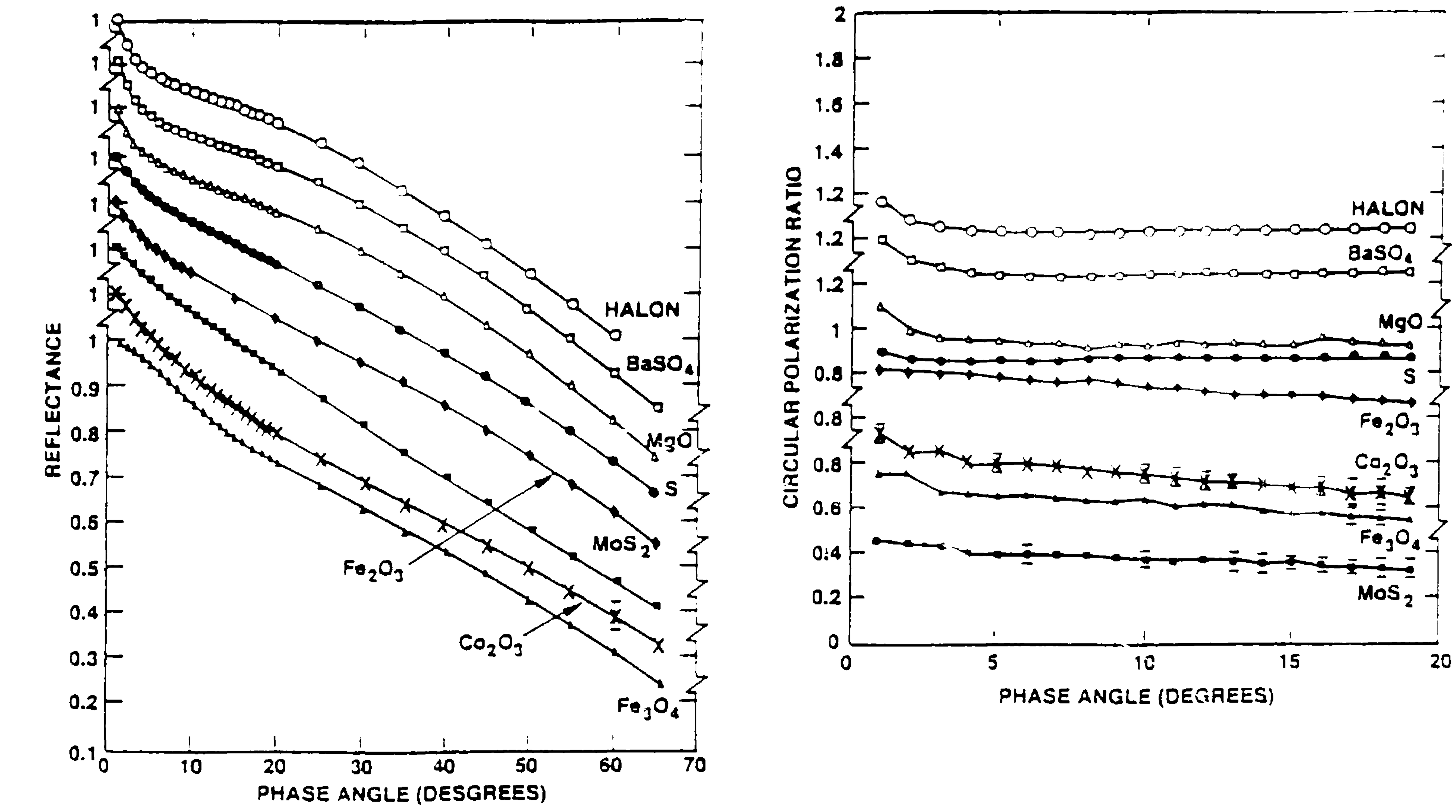

Figure 1a (left). Phase curves for eight powders. Reflectance as a function of phase angle is plotted for eight powders with single scattering albedos which range from < 0.99 (MgO) to 0.13 (CO_2O_3). Data are normalized at 1^0.

Figure 1b (right). Circular polarization ratios. Circular polarization ratio as a function of phase angle is plotted for eight powders shown in Figure 1. The circular polarization ratio increases with decreasing phase angle for all samples which is indicative of coherent backscattering.

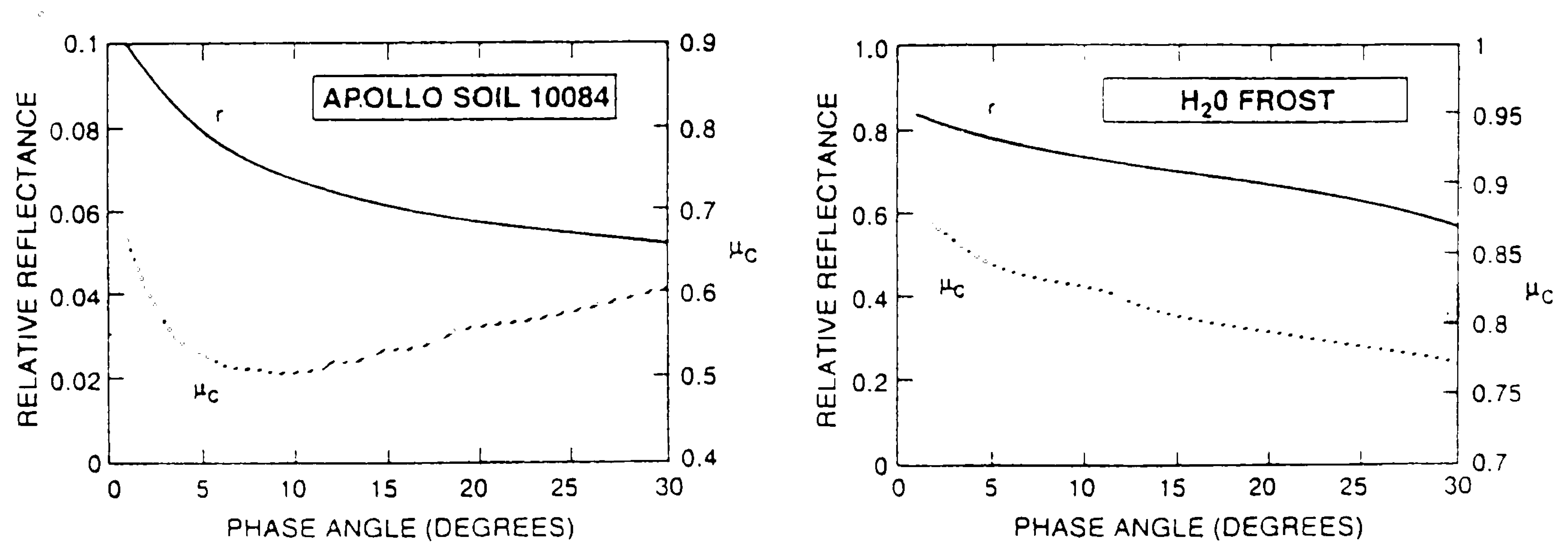

Figure 2a (left). Apollo soil and Figure 2b (right). H_2O frost-- Phase curves and circular polarization ratios. Reflectance (solid line) and circular polarization ratio (dashed line) is plotted as a function of phase angle. Coherent backscatter is observed.

We also examined a lunar soil sample (Figure 2a) and H_2O frost (Figure 2b). These samples also exhibit an opposition effect and an increase in the circular polarization ratio with decreasing phase angle. The H_2O frost represents an analogy for Saturn's rings.

4. Conclusions

The effects of the coherent backscattering opposition surge are present in all samples measured to date. The angularly narrow but intense opposition peak that we observe in the highly reflective materials cannot be explained by the shadow hiding process for the opposition effect. The incident light is multiply scattered in a highly reflective material and any shadows or voids would be illuminated and filled in. The reflected radiation would be a mixture of both senses of polarization. The increase in circular polarization ratio with decreasing phase angle, especially that seen in the highly reflecting materials, is consistent with coherent backscatter as the cause of the opposition effect.

Coherent backscatter appears to be a common process in powders. If small grains form a regolith on Saturn's macroscopic ring particles then the ring opposition surge may result from coherent backscatter of these grains. In the case of Saturn's rings, small grain sizes in the A and B rings may be on the order of 0.1 to 1 μm (Mishchenko and Dlugach, 1992). Future spacecraft studies of the rings by missions such as Cassini will provide a wider range of phase angle coverage of the rings which will increase our understanding of fundamental physical properties of the ring particles such as grain size, mean grain separation and albedo.

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