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CORNELL UNIVERSITY

Center for Radiophysics and Space Research

ITHACA, N.Y.

SEMI-ANNUAL STATUS REPORT

to the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

under

NASA Grant NSG 7606

"Effects of Photometric Geometry on Spectral Reflectance Measurements"

March 1, 1981--August 31, 1981

Principal Investigator: J. Veverka
Co-Investigator: Jonathan C. Gradie

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I. SUMMARY OF RECENT PROGRESS

Our investigation of how spectral reflectance properties of powdered materials are affected by photometric geometry continues to produce important results. Specifically, we have completed the following analyses.

A. We have demonstrated that reflectance curves do depend upon geometry (Gradie et al., 1980a,b).

B. We have compared various forms of photometric functions and have shown that $I_\lambda(\mu,\mu_o) = A_\lambda \frac{\mu_o}{\mu + \mu_o} f_\lambda(\alpha) + B_\lambda \mu_o$ is adequate to first order (Gradie and Veverka, 1981b).

C. We have used this photometric function to complete an initial study of the phase coefficients of various materials (Gradie and Veverka, 1982a) and to complete an initial study on how the shape of a body affects the spectral reflectance properties (Gradie and Veverka, 1981a,b, and 1982b).

D. We have studied the adequacy of the photometric function above (under B) for Mars-like analogs provided by Ray Arvidson, of Washington University.

E. We are currently converting our goniometer system to the new computer driven mode. All of the Hewlett-Packard equipment has arrived, and the multiprogrammer is currently being wired to the goniometer stepping motors for initial testing.

F. We have begun the initial steps in our study of highly reflecting materials, e.g., sulfur, and our extension of measurements to large phase angles. We will begin our study of the phase dependence 0.95 micron feature in meteorite spectra as soon as the computer controls are integrated with the goniometer.

II. DETAILS OF RECENTLY COMPLETED PROGRAMS

The following is an elaboration of the work outlined in Section 1.

A. We have successfully demonstrated the degree to which photometric geometry affects spectral reflectance curves The majority of this work was completed during the previous grant year, but serves as a useful base for the topics which follow. Gradie et al. (1980a,b) showed that the effects of scattering geometry are common for a variety of materials (e.g., Allende, basalt, hedenbergite, Bruderheim, sulfur, etc.), and particle size ranges (< 75 μm, 45-75 μm, 75-150 μm). Such effects are illustrated in Fig. 1 for basalt (Gradie et al., 1980b).

B. Gradie and Veverka (1981b) have concluded that a photometric function of the form $I_\lambda(\mu,\mu_0) = A_\lambda \frac{\mu_0}{\mu + \mu_0} f_\lambda(\alpha) + B_\lambda(\alpha)$ is adequate for describing the scattering properties of low and moderately reflecting materials

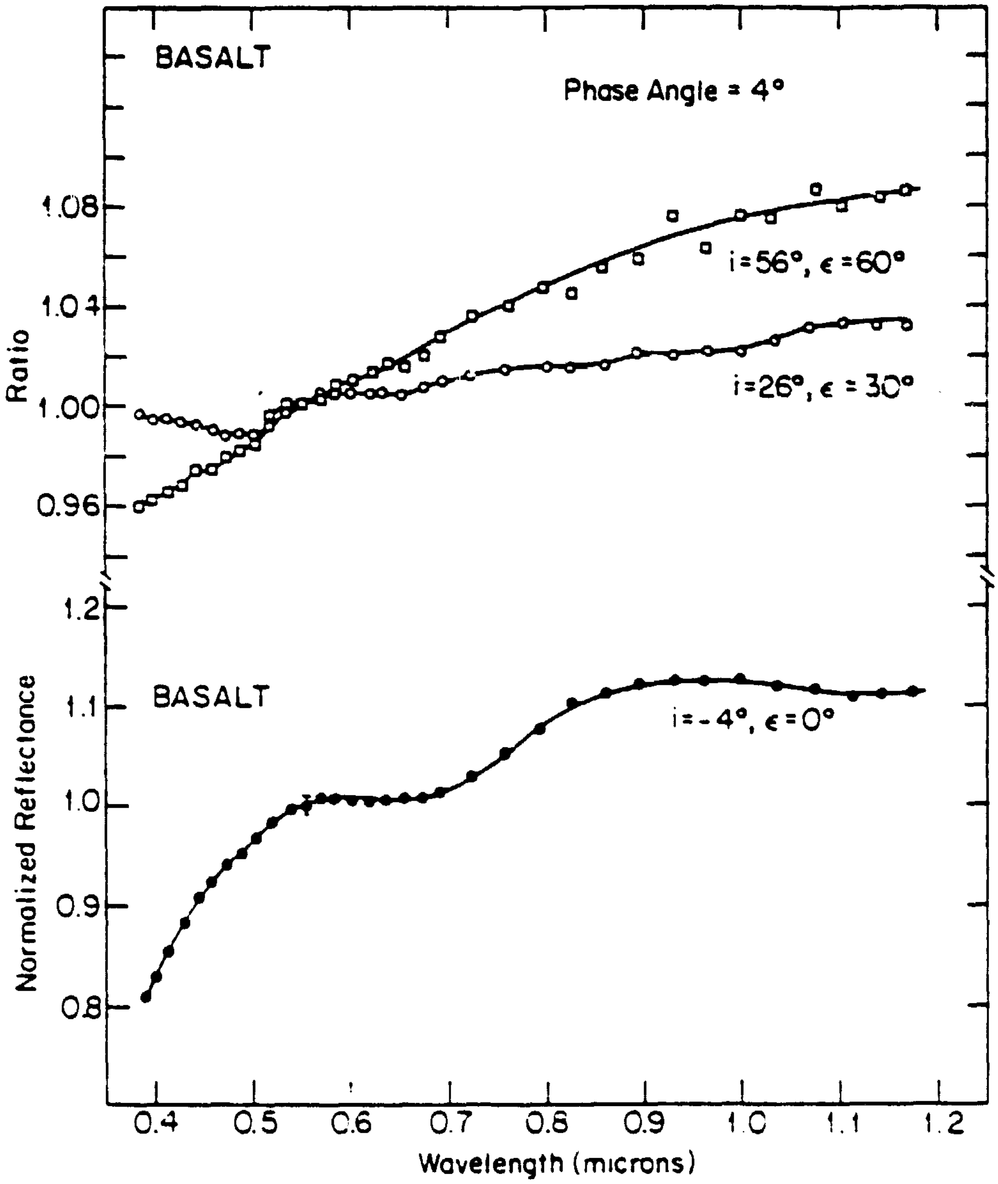

Figure 1. The spectral reflectance of basalt (particle size 45-75 microns) normalized at λ = 0.55 microns at an incidence angle, i = 4° and an emission angle, ε = 0°, is shown in the lower half. The upper half of this figure illustrates the ratio of the spectral reflectance at i = 4°, ε = 0° to the spectral reflectance viewed at two other arbitrary geometries.

after comparing a variety of photometric forms including the complex forms proposed by Hapke (1981) and by Goguen (1981). This result is directly applicable to a variety of problems of current interest to solar system studies. Fig. 2 shows the match between the spectral reflectance calculated and observed for an arbitrary geometry.

We have shown that the spectral reflectance curves of flat laboratory samples (Allende, basalt and Bruderheim) measured with a bidirectional geometry ($i = 4°$, $\varepsilon = 0°$) are redder than those measured with an integrating sphere. Gradie and Veverka (1982a) conclude that, except for samples of very low reflectivity which show little spectral difference between methods and samples of very reflectivity for which the above photometric function may not apply, reflectance curves obtained with an integrating sphere provide a better match to a planet at small phase angles ($\alpha \sim 4°$) than do reflectance curves obtained with a bidirectional geometry ($i = 4°$, $\varepsilon = 0°$). However, we find that the opposite is true as the phase angle increases. An example is shown in Fig. 3 (a and b).

C. We have applied the above photometric function and the photometric parameters obtained in earlier studies to investigate the wavelength dependence of phase coefficients and the changes in spectral reflectance curves due to body shape.

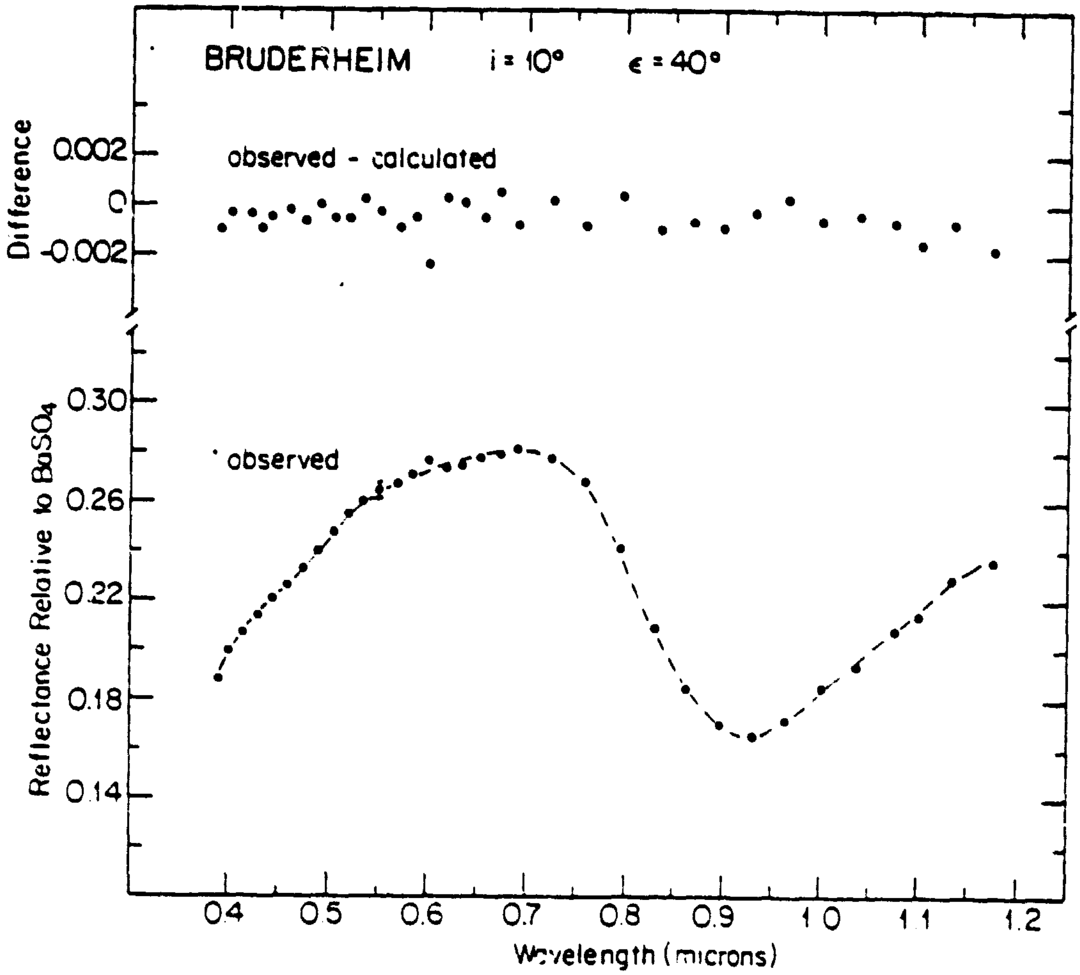

Figure 2. A comparison between the observed spectral reflectance (lower curve) of the Bruderheim sample and the spectral reflectance calculated according to Eqt. (2) using coefficients $A_\lambda f_\lambda(30°)$ and B_λ. The difference between the two spectral reflectances is shown in the upper half.

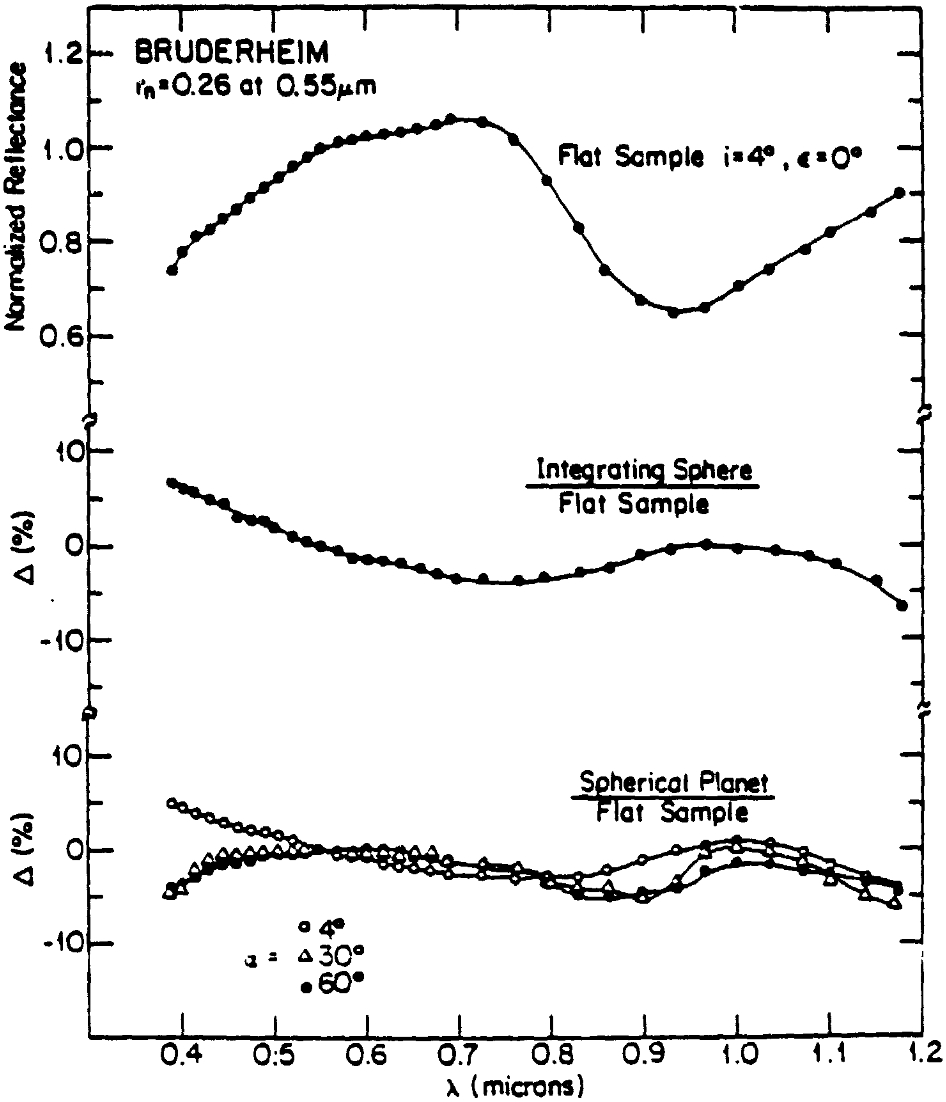

Figure 3a. At top is the normalized spectral reflectance (λ = 0.55 microns) of the ordinary chondrite Bruderheim (particle size 45-75 microns) observed at i = 4°, ε = 0°. The middle curve is the percent difference between the normalized spectral reflectance calculated for a measurement of the flat sample by an integrating sphere and the normalized spectral reflectance of the flat sample observed at i = 4° and ε = 0°. At the bottom is the difference in percent between the calculated normalized spectral reflectance of a Bruderheim-covered spherical planet at three phase angles, α, and the normalized spectral reflectance of the flat sample at i = 4°, ε = 0°.

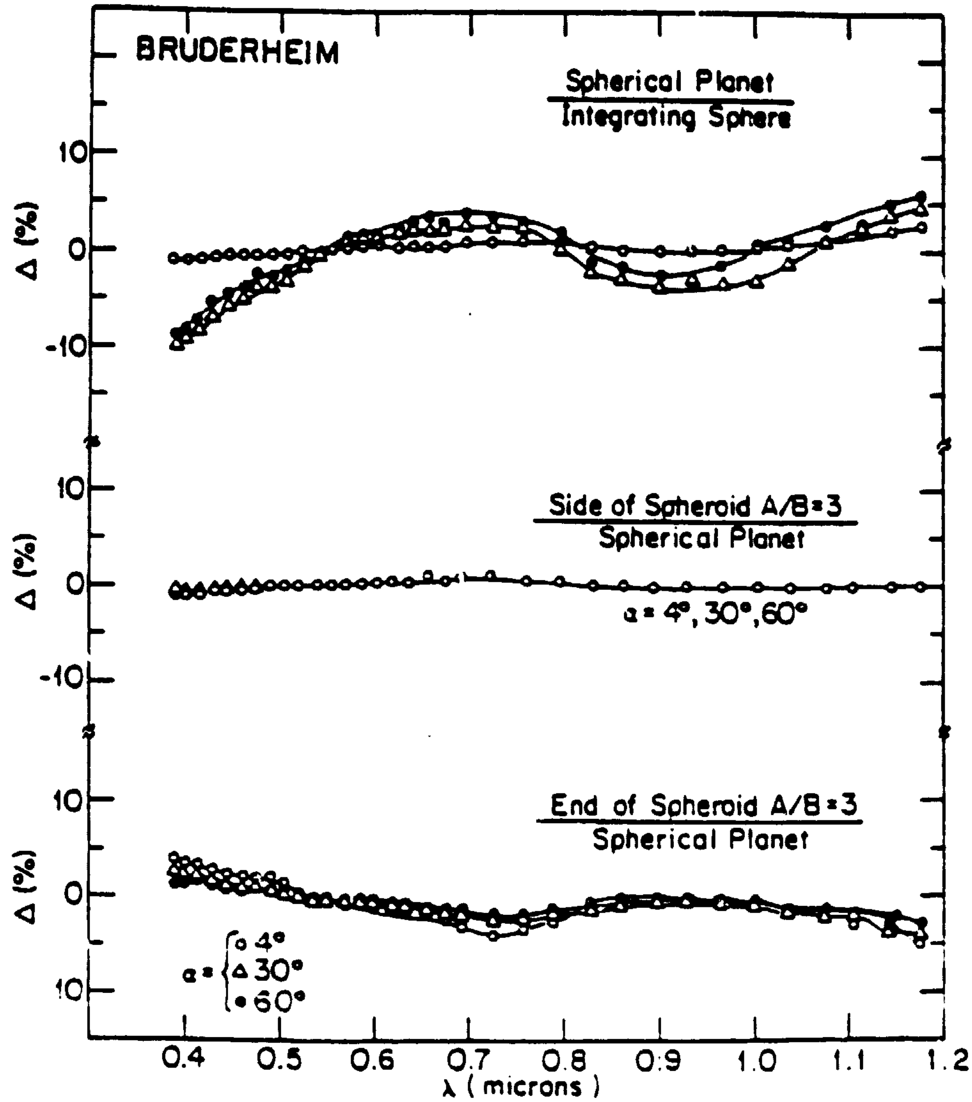

Figure 3b. At top is the difference in percent between the calculated normalized spectral reflectance of a Bruderheim-covered planet at three phase angles, α, and the normalized spectral reflectance calculated for a flat sample measured by an integrating sphere. The middle curve illustrates the difference in percent between the normalized spectral reflectance of the side of a Bruderheim-covered spheroid (axes B = C and A/B = 3) at three phase angles, α, and the normalized spectral reflectance calculated for an Allende-covered spherical planet viewed at the same time. The bottom curve illustrates the difference in percent between normalized spectral reflectance calculated for the end of the spheroid at three phases, α, and the spherical planet.

Gradie and Veverka (1982b) found that the wavelength dependence (0 4 to 1.2 microns) of the phase coefficients of the C3 carbonaceous chondrite Allende, the ordinary chondrite (L6) Bruderheim, and a basalt, qualitatively match the observed wavelength dependent of the phase coefficients of the S asteroids, the C asteroids and the Moon, respectively. Also, model calculations of surface roughness indicate that the systematic differences between the phase coefficients of S and C asteroids reflects primarily differences in composition and not in surface roughness. We have also found that absorption band depths can be significantly affected by geometry, as shown in Fig. 4, where an observed change in the 0.95 micron band depth with phase angle (in the case of asteroid 1566) is compared with our model of Bruderheim, over a similar range of phase.

We have also investigated the effects of body shape on spectral reflectance curves. Gradie and Veverka (1981a) point out that color-lightcurve effects on order of several hundredths of a magnitude may be due to body shape rather than variations in surface composition. This result must be used cautiously, since the effects are small and depend upon the degree of asphericity of the body. Gradie and Veverka (1981b) extend this analysis to other materials (Fig. 3b).

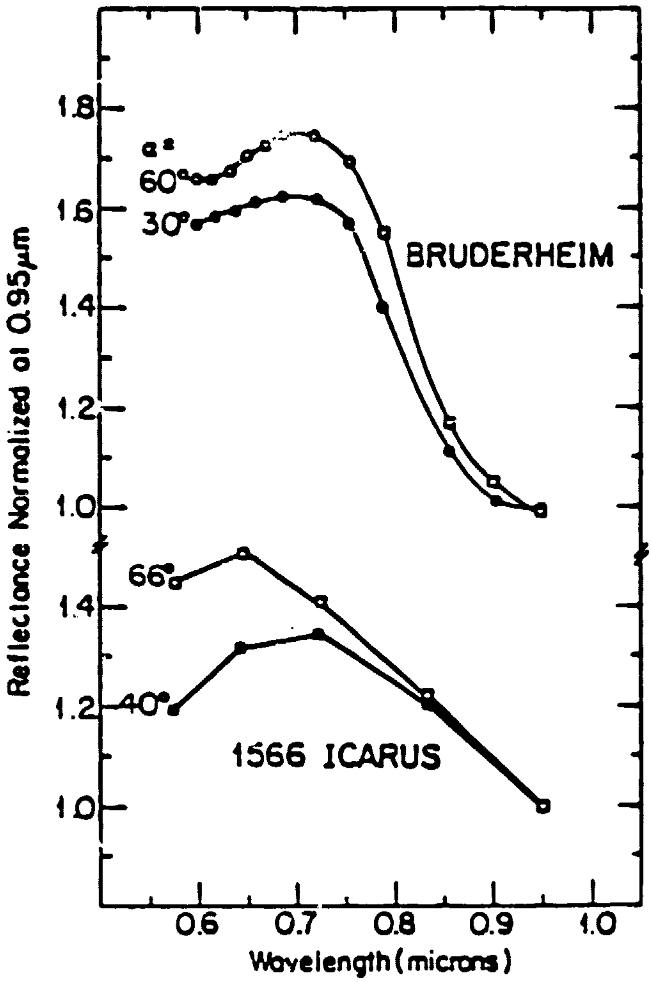

Figure 4. The spectral reflectance, normalized at 0.95 microns, of the Bruderheim-covered planet at 30° and 60° phase, is shown at top. Below is the change in the spectral reflectance, normalized at 0.95 microns, of the asteroid 1566 Icarus observed between 66° and 30° phase.

III. DETAILS OF WORK IN PROGRESS

The following is an elaboration of some of the current tasks outlined in Section I.

D. We are currently applying our previous results to Mars-analogs supplied by Dr. Ray Arvidson of Washington University. We are fitting various photometric functions to our data to determine if a more complicated function such as suggested by Hapke (1981) is required for these more highly reflecting materials. An example of this work is shown in Fig. 5.

E. The conversion of our goniometer to the computer-driven mode is proceeding smoothly. All of the Hewlett-Packard supplied materials have arrived in good working order, but the multiprogrammer was delivered significantly later than pronounced. We expect that the conversion will be completed by the end of October 1981.

The HP-85 computer has already been programmed for a variety of reduction routines. Fig. 6 is an example of the type of immediate graphic result we expect from our computer-driven mode. The reflectance is that of a sample of sulfur-glass prepared by Gradie et al. (1981) in a follow-up study of their analysis of the spectral properties of Amalthea (Gradie et al., 1980).

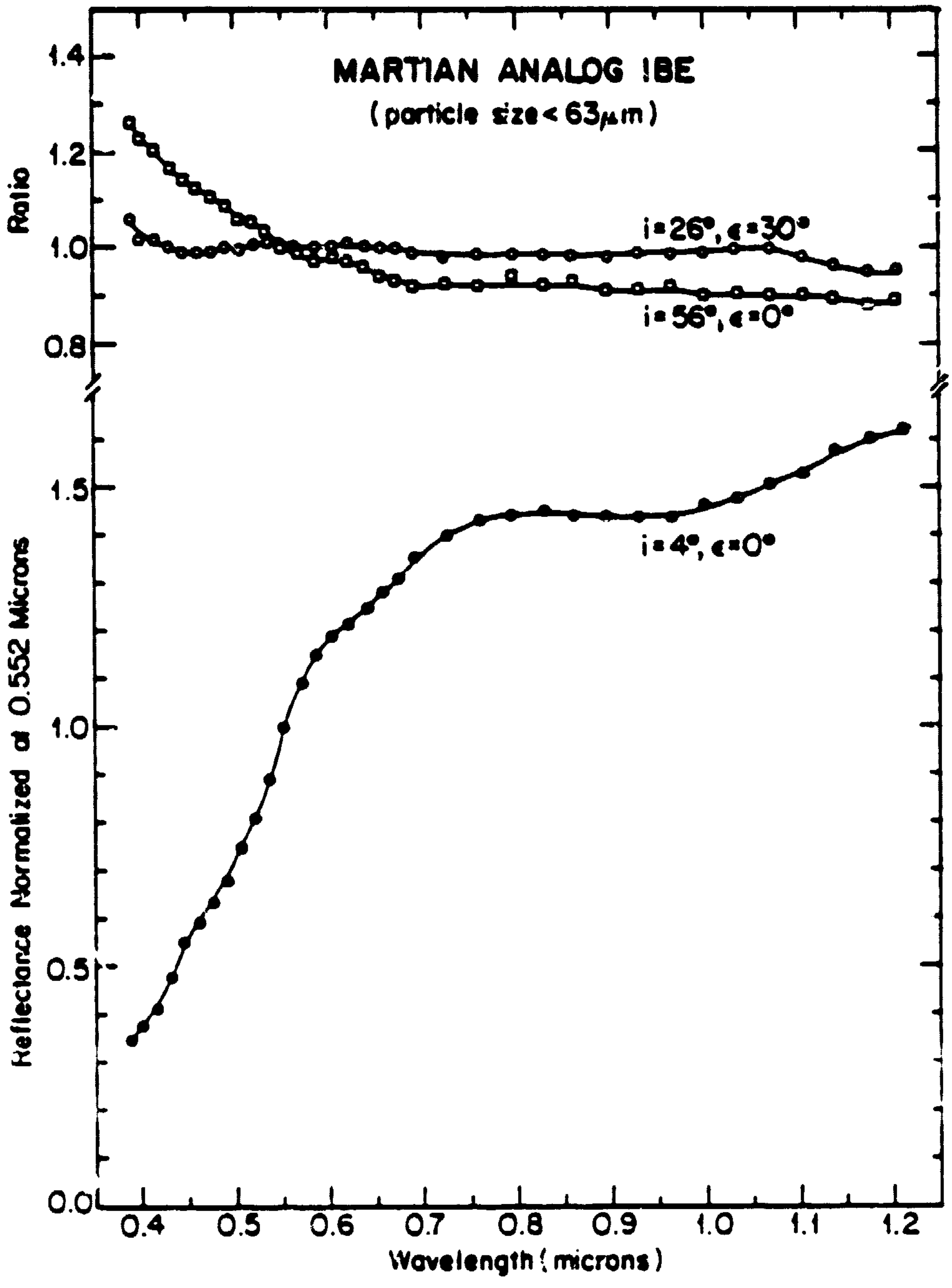

Figure 5. The variations in normalized spectral reflectance of a martian soil analog. The lower curve is the spectral reflectance of this sample at i = 4°, ε = 0°, the upper curve is the spectral reflectance at two arbitrary geometries ratioed to the spectral reflectance at i = 4°, ε = 0°.

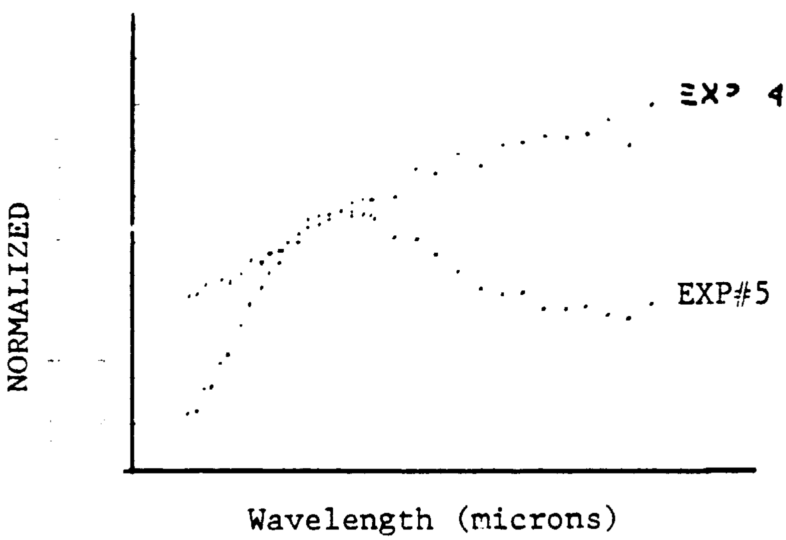

Figure 6. The spectral reflectance normalized at 0.552 microns of two samples of basaltic glasses formed in the presence of large quantities of sulfur. The difference in spectral reflectance between Exp #4 and Exp #5 reflects primarily the slower cooling rate for Exp #5 and the subsequent formation of olivine micro-crystals.

F. We are beginning the study of very bright materials, the foremost example of which is sulfur. Fig. 7 illustrates the dramatic changes with geometry in reflectance curves that do occur. The study requires careful control of the standard (in our case, $BaSO_4$ paint). We have considered using a Halon standard, as suggested by Dr. M. Gaffey at the University of Hawaii, but have concluded that the photometric properties of this substance over a wide range of geometries are not as simple (i.e., Lambertian) as those of the $BaSO_4$ paint.

As soon as the conversion to the computer-driven mode is completed, we will extend our measurements to larger phase angles, and initiate our survey of changes in the spectral parameters of the 0.96 micron feature over a wide range of geometries.

IV. CONCLUSION

The project continues to progress at a satisfactory rate and is yielding valuable results needed for the full interpretation of the spectral reflectance curves of solar system objects. Very soon, the new computer-driven mode of our goniometer will be operational, and we expect that the rate of production of measurements will increase substantially.

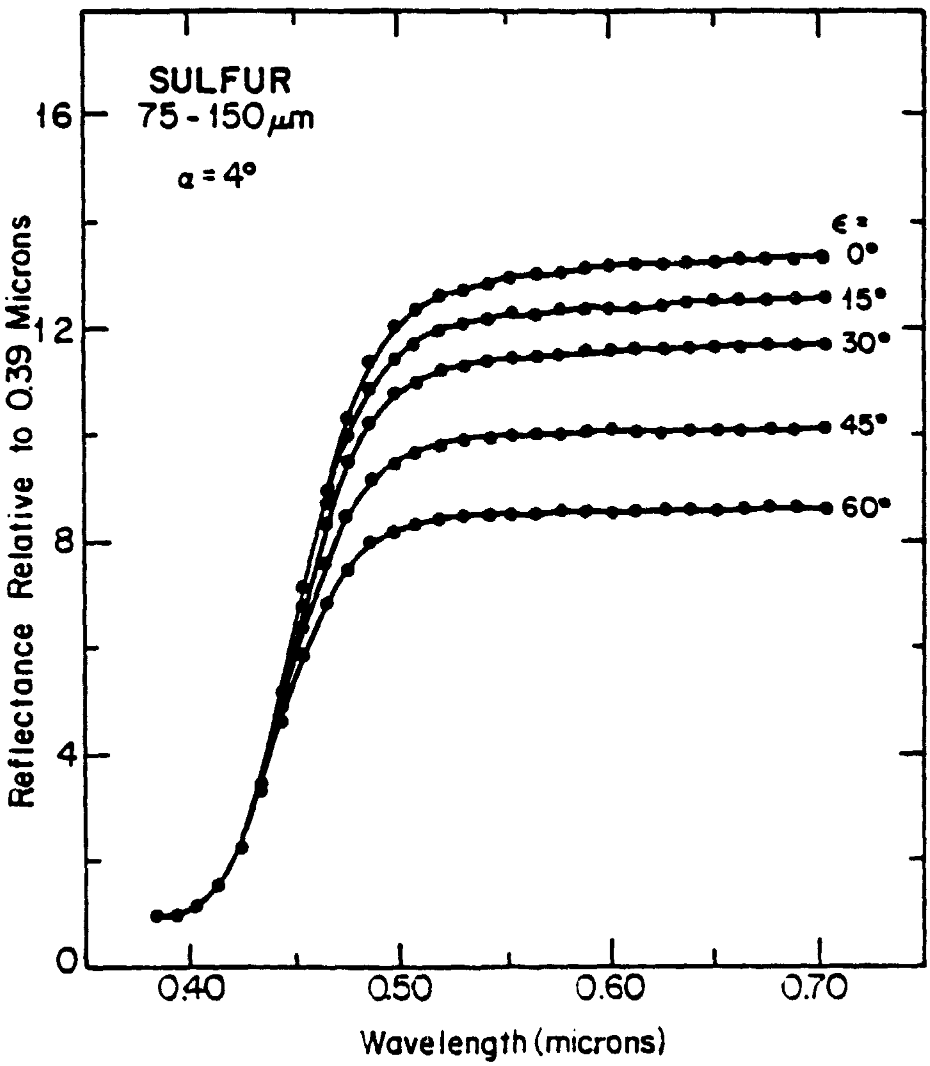

Figure 7. The ε dependence of the reflectance spectrum of sulfur.

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