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Compositions of Near-Earth Asteroids

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Abstract

The goal of this study is to determine whether any of the near-earth asteroids contain water-bearing phyllosilicate (clay) minerals. If these minerals are present, they would provide a readily available source of water for propellant generation and use in life support systems. Telescopic detection of water on the near-earth asteroids is complicated because thermal emission from the asteroid itself masks the diagnostic absorption features for objects this close to the sun. Sophisticated thermal models will be necessary to determine whether the absorption features are present. This year, we have continued development of these models and have obtained more telescopic data to test the models.

Introduction

The CI1 and CM2 carbonaceous chondrite meteorites are known to contain clay minerals in their matrix. In fact, the CI1 meteorites contained enough water that it was able to migrate in the parent body, dissolving minerals and redepositing them as evaporite veins. Asteroidal size bodies with these compositions would prove rich sources of water and oxygen, and the resources might be easier to extract from clays than from other oxides. Reflectance spectra of these meteorites are similar to telescopic spectra of some of the C-class asteroids in the main asteroid belt, implying similar mineralogy. Unfortunately, all of these asteroids are extremely dark, which makes it difficult to measure accurate reflectance spectra. The dark components on their surface also mask the presence of other components in their reflectance spectra because the darkest components dominate the reflectance spectra of a mixture of minerals. In addition, the features diagnostic of water occur in the 3-4 μm wavelength region. In the main asteroid belt, this wavelength region is still dominated by reflected light, although thermal emission makes a significant enough contribution that is must be modeled before the reflectance spectrum can be analyzed (Fig. 1). Careful telescopic work has found water absorption features in the telescopic spectra of some of the C-class asteroids, but not all. This makes it impossible to assume that all C-class asteroids will contain hydrated minerals. Recent work by Dan Britt has suggested that some of these asteroids (the ones that do not show the water absorption features) may actually be similar in composition to ordinary chondrites, which do not contain any hydrated phases.

The near-earth asteroids are much more accessible than the main belt asteroids, so it is desirable to determine if any of the C-class objects in the near-earth population contain clays. This is a difficult problem for two reasons. First, the near-earth asteroids are small, and the C-class asteroids are dark, which makes them very difficult to observe telescopically. Second, the near-earth asteroids are much nearer to the sun than the main belt asteroids, which makes them significantly warmer. This shifts the peak in their thermal emission to much shorter wavelengths, thus the thermal component of the asteroids dominates the spectrum in the 3-micron region where the diagnostic water absorption feature is present. Simple thermal models are not accurate enough to remove this thermal contribution.

Hapke has proposed the first model which treats the reflected and emitted radiation simultaneously, which offers the best opportunity for modeling the spectra of the near-earth asteroids. The model is an application of radiative transfer theory to particulate surfaces. It includes terms for the absorption and scattering properties of the component minerals, the photometric geometry, and the physical properties of the surface. Reflectance spectra can be calculated from the model and compared to measured spectra, or the model can be fit to observational data, making appropriate assumptions about the unknown parameters. Parts of this theory have been, and are being tested extensively, but the thermal terms are new and relatively untested.

We have proposed to apply this theory to analyze telescopic spectra of C-class near-earth asteroids to determine their water content. Before this is possible, we must test the theory to determine its validity and sensitivity in better understood applications. This year, we have done much to advance our understanding of the theory.

Results for This Year

Software Development. This year Marcia Nelson has ported a major program to the Planetary Image Resource Center computers at the Lunar and Planetary Laboratory. This program calculates many of the terms in the published Hapke theory, and fits the equations to reflectance spectra to determine parameters in the theory of interest, such as the grain size and abundance of component minerals.

Modeling. Last year, Marcia Nelson worked on three modeling applications to improve our understanding of the Hapke model. In the first project, she showed that the theory can calculate spectra of mineral mixtures directly from the optical constants of the components, and given the end members, the mineral abundances can be determined fairly accurately from the optical constants. In the second project, she used the theory to determine the modal composition of the surface of Vesta, assuming end members from the pre-existing literature. In the third project, she calculated spectra of some lunar analogue mineral mixtures to study the mixture systematics.

This year, she has been continuing to analyze her previous results. The previous Vesta analysis was adequate, but not as good as had been hoped. Initially, the problems had been attributed entirely to the deficiencies in the mineral chemistry of the end members Nelson was able to obtain from the literature and the lack of information on the grain size. The differences in mineral chemistry definitely contributed to the problems, but on closer examination of the initial failed attempts, she realized that the uncertainty in the grain size was also a major contributor. No information was available on the grain sizes of the minerals chosen as end members. A uniform grain size was assumed for all components which was reasonable for a regolith, assuming asteroid regoliths are similar to that of the Moon. This year, it was realized that the grain size of one of the components was probably much larger than the one assumed, because the laboratory spectrum was unusually dark for that mineral. This distorted the calculated abundances because the fitting program was forced to add excessive amounts of the brighter components to match the continuum reflectance.

Further analysis showed that in all three of these applications, the grain size had a major effect on the model. This is a parameter which had not really been examined systematically in the theory. We didn't have a laboratory available to create an ideal test set of spectra, so she found ways to learn as much about this problem as possible with the spectra obtained for the other projects.

We had all of the necessary data for a complete analysis of the single grain size fraction used in creating the samples for the first project. Nelson measured the actual grain size of the samples from a number of scanning electron microscope images of the samples and used these to calculate the average grain size. This had been used in the initial calculation of the mineral abundances. She then used the software ported this year to fit the laboratory spectra to determine what grain size provided the best model fit. The grain size determined by the fit differed insignificantly from that determined by direct measurement. She next made histograms of the actual grain size measurements. The theory assumes spherical grains, but the actual measurements of the length and width showed a bimodal distribution. She determined the relative areas under the two peaks and calculated spectra for mixtures of grains of sizes corresponding to the two peaks and abundances proportional to their areas. These spectra were virtually indistinguishable from those calculated using a single average grain size (Figures 2 and 3).

This work has shown several things. First, it has proven that the theory is using the actual average grain size, and not some imaginary grain size determined by the mean optical pathlength of the light in the grains. It has also shown that an average grain size is sufficient to obtain valid results for a narrow grain size fraction. And it has shown that the theory results are extremely sensitive to the grain size. This means that a reasonable range of grain sizes will have to be used to create a series of possible results when the model is applied to real surfaces where the grain size is unknown. Nelson is in the process of doing this with the Vesta model at this time.

Observing. This year, we have had four observing runs (two at the MMT and 61" near Tucson and two at the IRTF in Hawaii), which were partially funded through NASA Planetary Astronomy. Useful data were obtained on half of these runs. Telescopic spectra of several asteroids were obtained over 1-3.5 μm wavelength range. These data will be used to test the models we are developing. The Vesta data will be used to test the complete theory next year.

Publications

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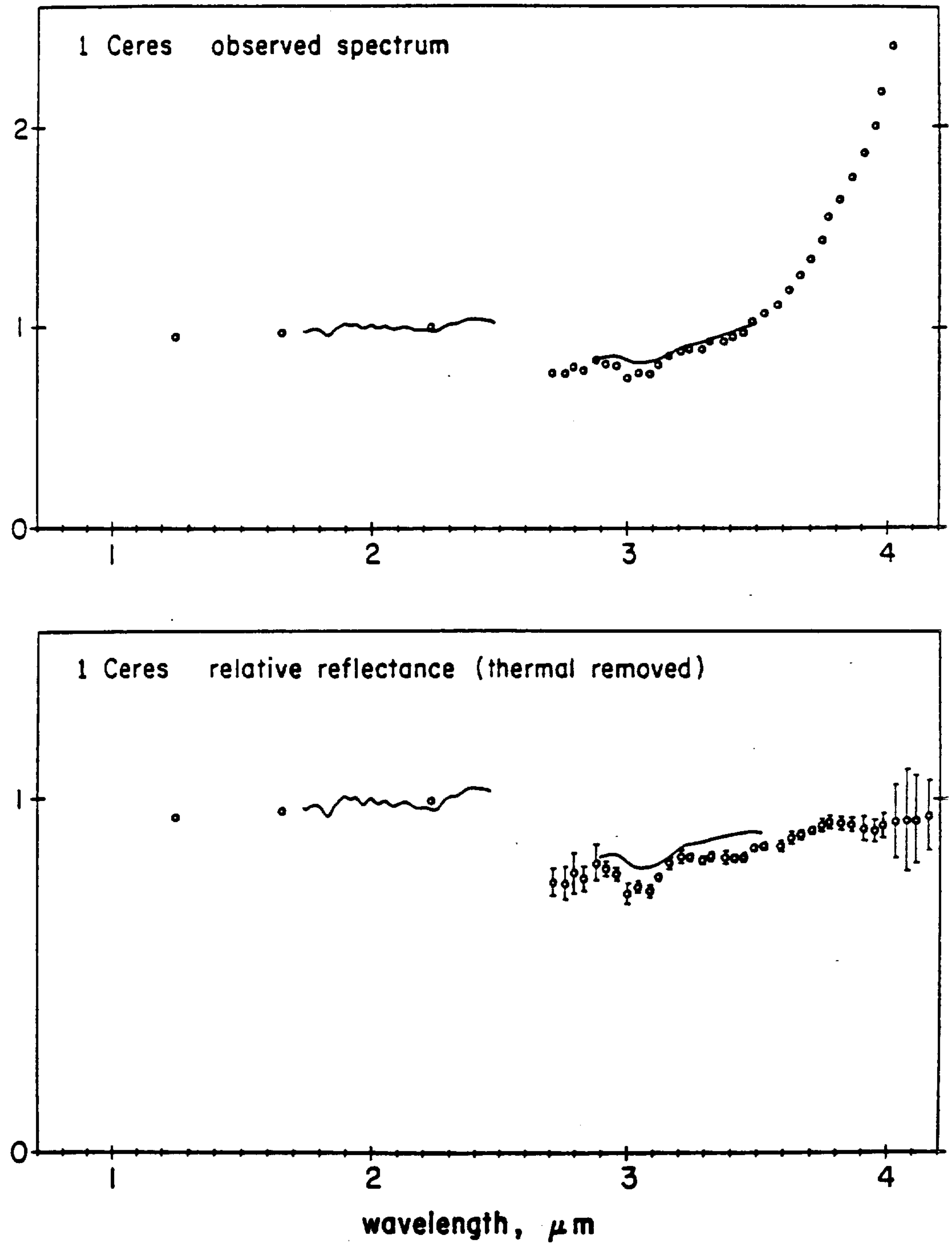

Fig. 1. Observations of the spectral reflectance of Ceres between 1 and 4 μm. The solid lines are high-resolution Fourier spectra and the circles are medium-resolution spectrophotometry. The upper curves are the observed spectra of Ceres, including the thermal emission from the asteroid at longer wavelengths. The bottom curves are the relative reflectance with the thermal emission removed using the "standard thermal model."

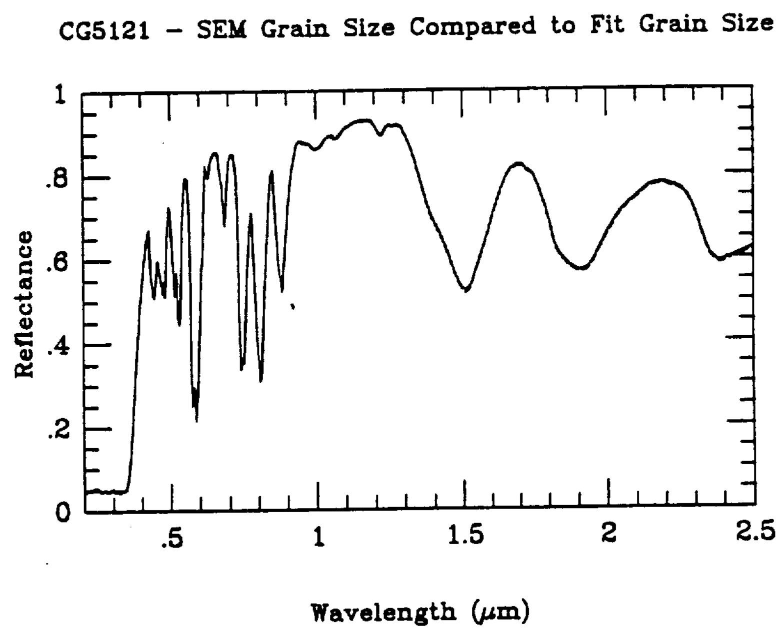

Figure 2. Calculated spectra of corning glass 5121. The solid line is calculated using the measured grain size and the dashed using the model grain size.

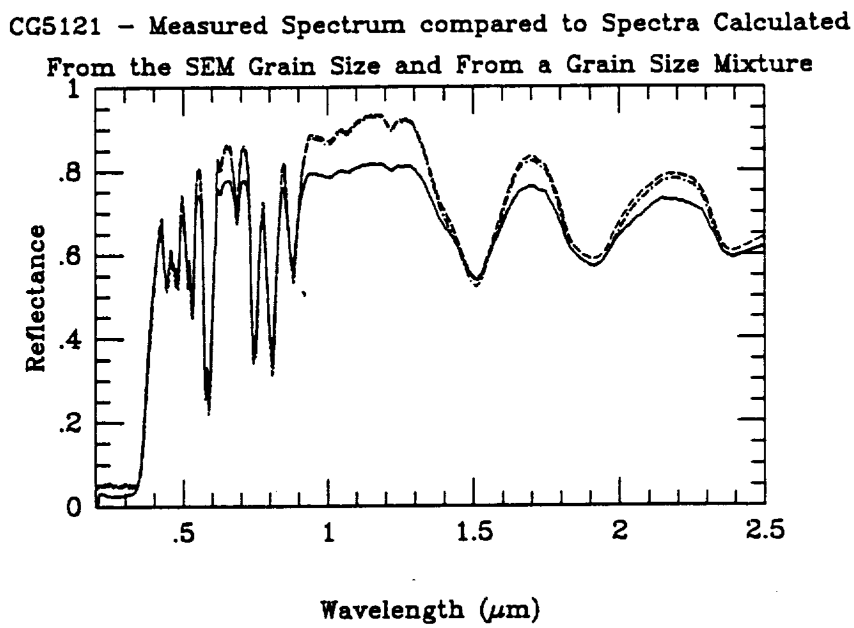

Figure 3. The measured spectrum of corning glass 5121 is plotted as a solid line. Spectra calculated using the measured grain size (dashed) and the grain size mixtures (dash-dot) are plotted as dashed lines. The calculated spectra are virtually identical.

IV. SYSTEM AUTOMATION AND OPTIMIZATION