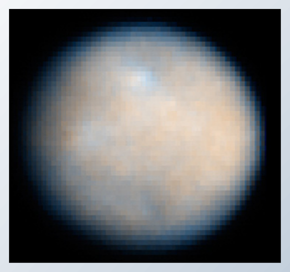

RADIATIVE-TRANSFER MODEL REFLECTANCE SPECTRA OF POTENTIAL CERES MINERAL ASSEMBLAGES

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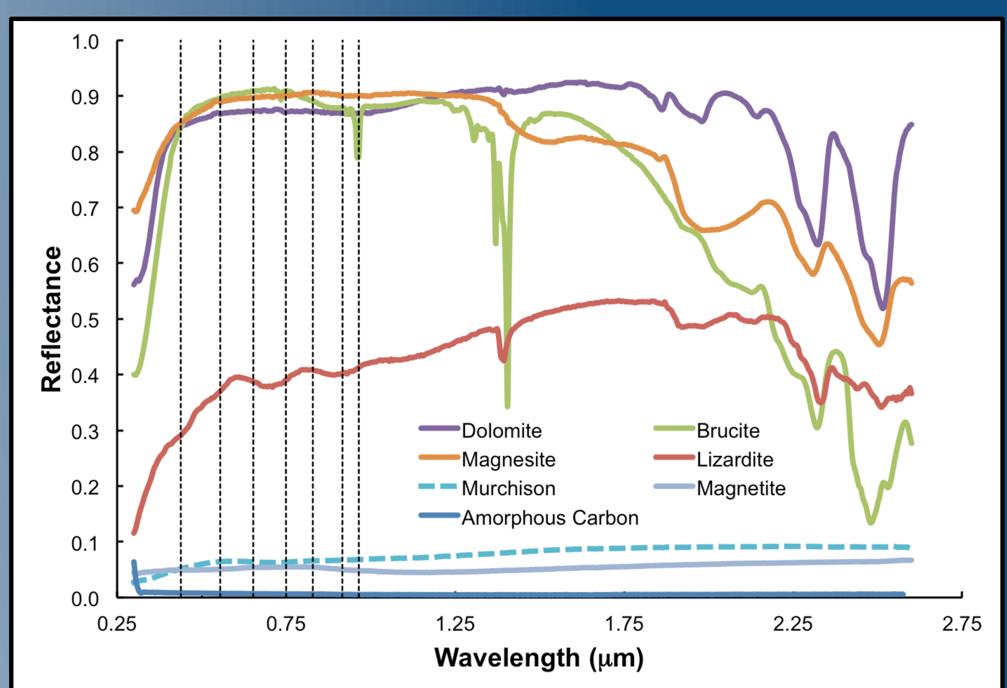
0. Introduction

The *Dawn* spacecraft will rendezvous with the dwarf planet Ceres in 2015 [1]. The surface of Ceres is inferred to have a composition resembling that of carbonaceous chondrite meteorites [e.g., 2], quite different from the volcanic and plutonic rocks of *Dawn*'s first target, Vesta. Reflectance spectra of Ceres in the visible to near-infrared (NIR) wavelength range obtained with Earth-based telescopes are mostly featureless, although spectral features in the mid-infrared have been used to identify carbonates and alteration phases such as brucite (magnesium hydroxide, $Mg(OH)_2$) [3]. The *Dawn* Visible and InfraRed (VIR) [4] imaging spectrometer will measure the reflectance of the cerean surface from ~0.4 to 5.0 µm. The seven bandpass filters (0.438, 0.555, 0.653, 0.749, 0.829, 0.917, 0.965 µm) of *Dawn*'s multispectral Framing Cameras (FC) [5] are optimized for characterizing the mafic silicate mineral assemblages (basalts and orthopyroxenites) found on Vesta. During portions of the Ceres mission in low-altitude orbit, operational constraints may limit the FC to use of as few as three of the filters. Here we use Hapke's radiative-transfer intimate mixing model [6] to predict spectra of assemblages of plausible Ceres minerals. We present FC spectral parameters and filter selections that may be most useful for mapping compositional differences on the cerean surface. Future studies will examine space weathering of Ceres analog assemblages.

1. Data and Model

We obtained laboratory ultraviolet (UV)-visible-near-infrared (NIR) reflectance spectra of analog minerals that are relevant to Ceres [3, 7] from the RELAB public database [8]. These include brucite, lizardite (a hydrous Mg-Fe phyllosillicate of the serpentine group), dolomite, magnesite, magnetite, and amorphous carbon, as well as the carbonaceous chondrite Murchison. We also examine the effects of water frost, which could be present at high latitudes on Ceres. Our Hapke spectral mixing model is adapted from one employed for a variety of lunar and meteoritic studies [9]. To compute model reflectance spectra, we first converted the RELAB reflectance spectra to single-scattering albedo. The single-scattering albedo of water ice was calculated from published optical constants [10]. All model grain sizes were assumed to be 40 µm. The end-member reflectance spectra over the wavelength range 0.3 to 2.6 µm are shown in **Fig. 1**.



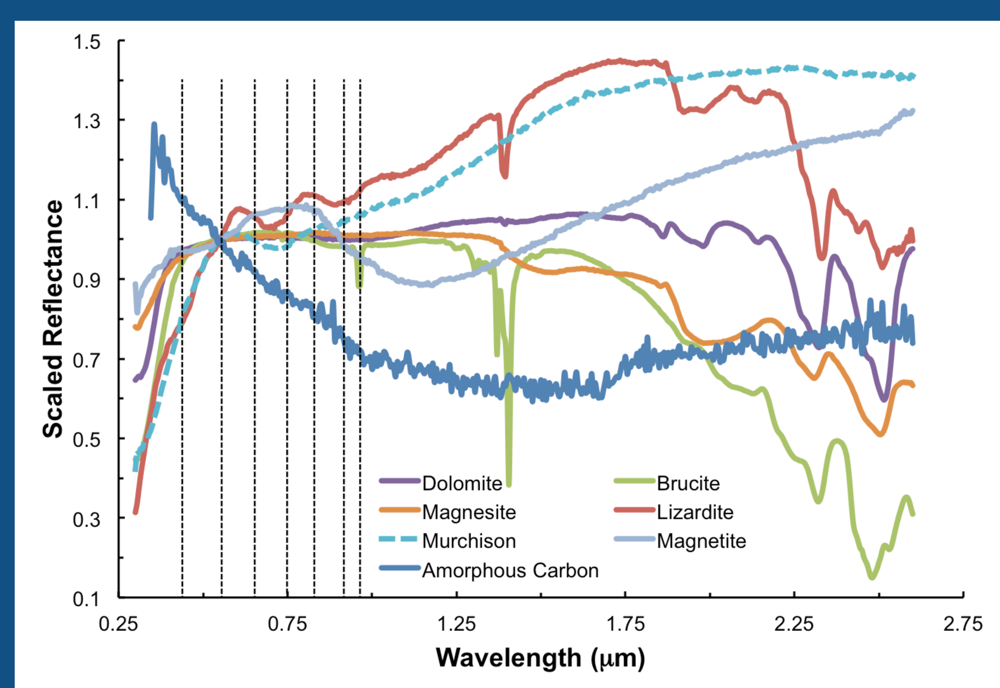
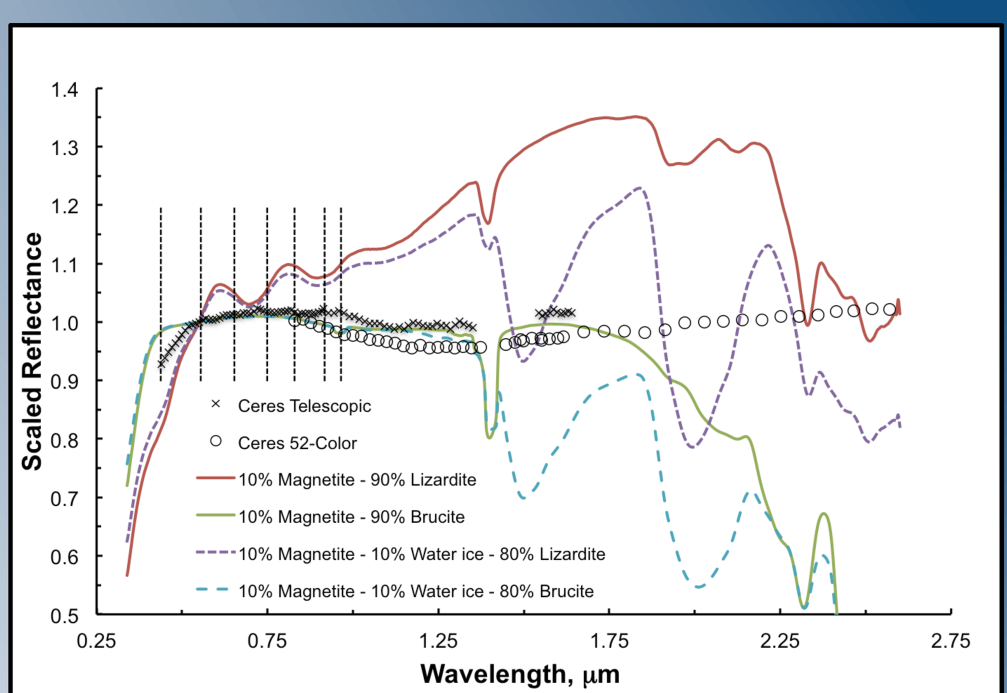


Figure 1. Laboratory reflectance spectra for Ceres analog minerals and for the Murchison carbonaceous chondrite meteorite. Vertical lines mark the center wavelengths of the seven *Dawn* FC filters. Absolute spectra (*left*) emphasize albedo differences. Scaled spectra (*right*) highlight shape and slope differences.



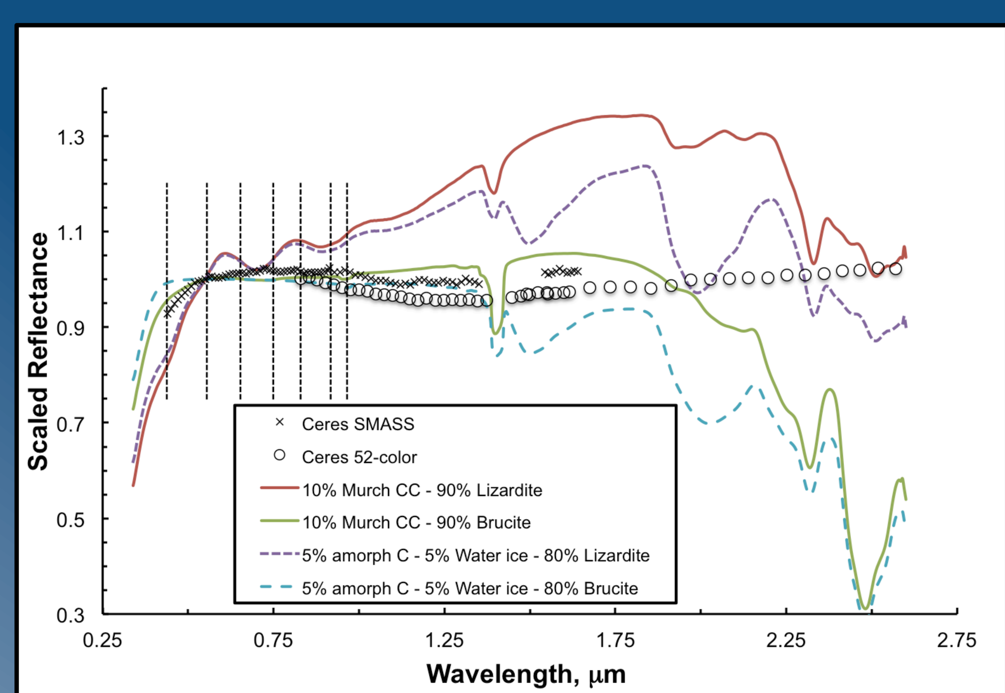


Figure 2 (left) and 3 (right). Model reflectance spectra for mixtures of analog minerals, plotted with Ceres telescopic spectra [11, 12, 13]. Spectra are scaled to 1.0 at 0.55 µm. These mixtures have absolute reflectances higher than the Ceres global average (~0.1 at 0.55 µm), but help to illustrate mixing systematics.

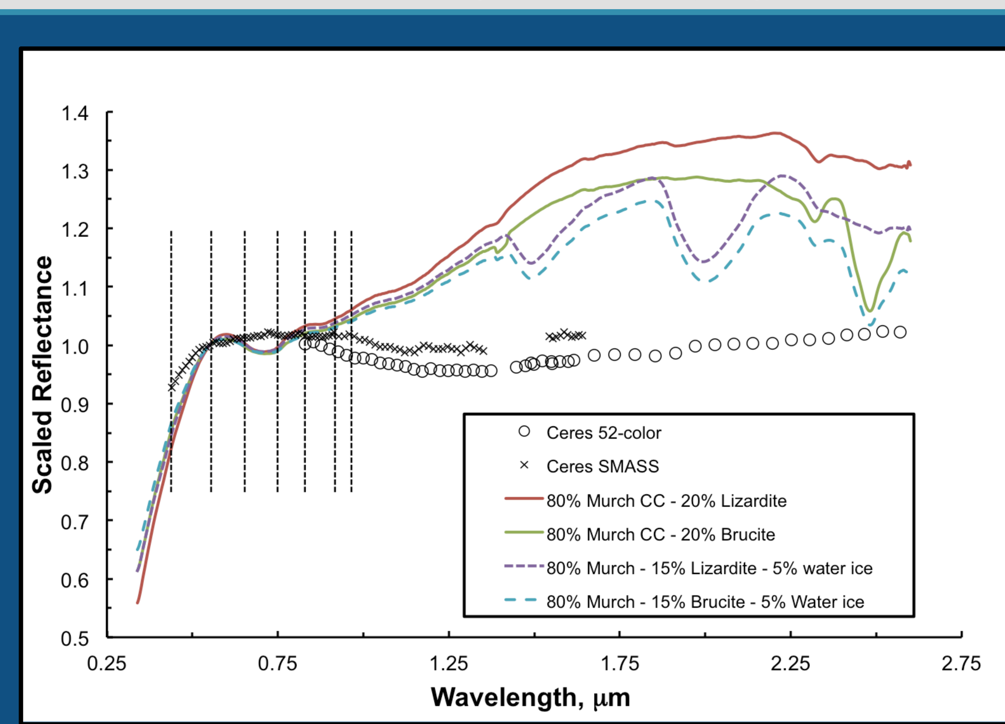
Acknowledgements

Ceres image is from the Hubble Space Telescope. Credit: NASA/ESA/SwRI/Univ. of Maryland/Cornell Univ./STScI. We thank Bin Yang (Univ. of Hawaii/IfA) for supplying the water ice optical constants of [10] in digital form. DTB thanks S. Lawrence (ASU) and P. Lucey (Univ. of Hawaii/HIGP) for sharing their radiative transfer code [9].

3. Model Mixture Spectra

Figures 2 and **3** present example model mixture spectra along with telescopic spectra of Ceres: the SMASS combined visible-IR telescopic spectrum [11, 12] and the 52-Color Survey spectrum [13]. The model spectra are scaled to unit value at 0.55 µm in order to emphasize shape and slope characteristics of the mixtures. Note that the disc-integrated albedo of Ceres at 0.55 µm is very low, about 10%. The mixture spectra in Figs. 2 and 3 have much higher albedos. Mixtures with lower, more Ceres-like albedos are presented in **Figs. 4** and **5**. The slopes of lizardite-bearing assemblages are too steep from ~0.7 – 2.0 µm to match Ceres well. Brucite, interpreted to be present on Ceres based on a feature at 3.06 µm [3], helps with the turn-down into the UV, but some other phase with a strong UV down-turn is likely present.

The addition of small amounts of water ice to the mixtures (Figs. 2-4) produces prominent absorptions near 1.5 and 2.0 µm that would be measureable by *Dawn*'s VIR instrument. VIR's wavelength coverage will greatly assisting with compositional interpretations by simultaneously measuring the Vis-NIR characteristics of Ceres with the mid-IR (~2.7 – 5.0 µm).



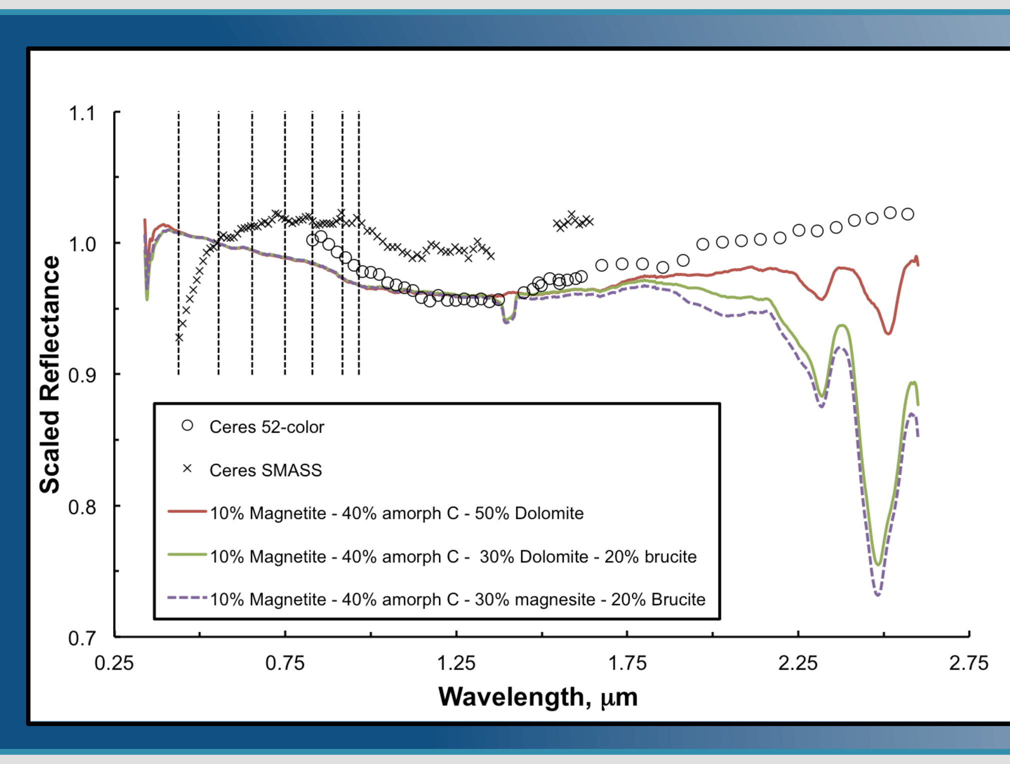


Figure 4 (left) and 5 (right). Model reflectance spectra for mixtures of analog minerals, plotted with Ceres telescopic spectra [11, 12, 13]. Spectra are scaled to 1.0 at 0.55 µm. The mixtures in these two plots have absolute reflectances roughly equal to the Ceres global average (~0.1 at 0.55 µm)

4. Filter Selection

To assess the ability of various FC filter combinations to discriminate among the analog minerals, we examined sets of reflectance ratios. **Figure 6** is a plot of the 0.438-µm/0.829-µm reflectance ratio against the 0.965-µm/0.829-µm for the mineral spectra of Fig. 1. Use of the 0.965-µm filter rather than 0.917 µm appears to better capture the absorption in lizardite centered near 0.97 µm. The 0.438-µm filter helps to measure the turn-down toward the ultraviolet, and can separate brucite-dolomite-magnesite from lizardite (Figs. 4-6). Similar degrees of separation are achieved if the 0.555- or 0.749-µm filters are substituted for 0.829 µm in the ratios. Thus, if operational considerations limit imaging to three filters, we would recommend 0.438- and 0.965-µm, plus one of 0.555-, 0.749-, or 0.829-µm.

5. Space Weathering

The surface of Ceres likely contains some iron-bearing phases (endogenic and/or exogenic) that could conceivably serve as the source of vapor-phase deposits of nanometer-size metallic iron ($npFe^0$) produced during bombardment by micrometeoroids and/or solar-wind ions. However, the $npFe^0$ might have little optical effect on Ceres' low albedo assemblage, though it could alter the slope to produce reddening. We plan to perform additional radiative-transfer modeling that includes the effects of nanophase iron on the analog Ceres mineral assemblages.

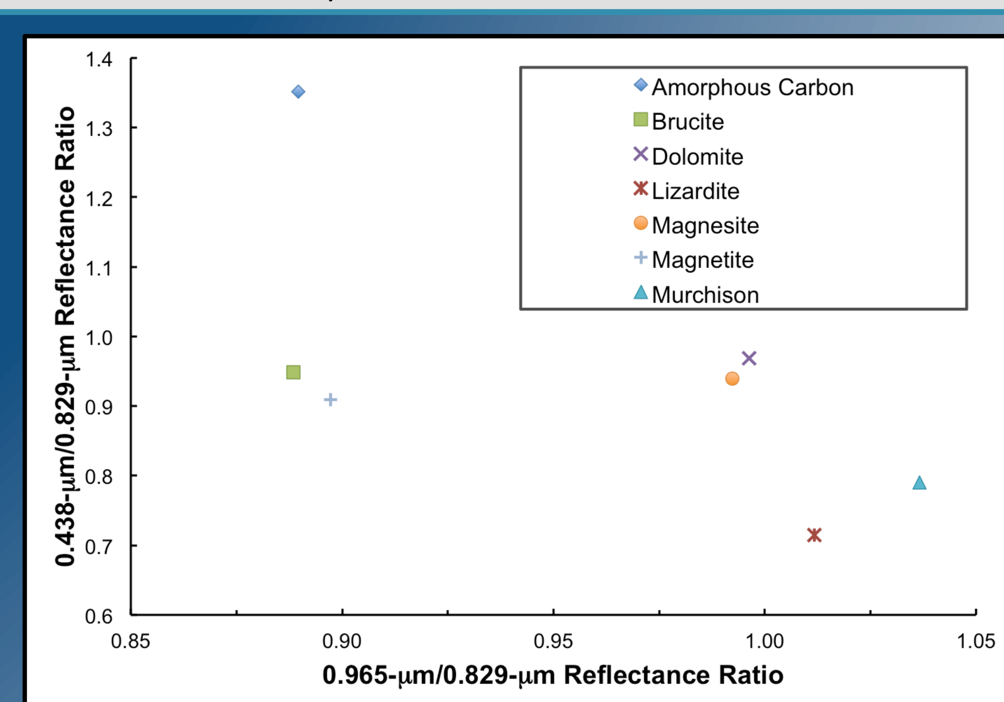


Figure 6. Spectral ratio plot for the analog spectra in Fig. 1. The 0.965-µm/0.829-µm reflectance ratio separates brucite from magnesite and dolomite.

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