

**SITTING AROUND WATCHING THE WORLD CERES: A ROTATIONAL STUDY OF THE INNERMOST DWARF PLANET.** A. S. Rivkin<sup>1</sup> and E. L. Volquardsen<sup>2</sup>, <sup>1</sup>JHU/APL, 11100 Johns Hopkins Rd., Laurel MD 20723 (andy.rivkin@jhuapl.edu), <sup>2</sup>Institute for Astronomy, University of Hawaii, Hilo HI 96720.

**Motivation:** It has been known since the 1920s that the asteroid 4 Vesta has large-scale compositional variation [1], easily seen as spectral differences as it rotates [2,3]. Similar variation has been sought on many objects since then, and occasionally found [4-6].

The asteroid (or dwarf planet or something) Ceres has given some mixed signals with regard to whether we should expect surface spectral variegation. Its lightcurve has an extremely low amplitude, indicating no large-scale albedo contrasts greater than a few percent and a relatively round shape. However, ground-based adaptive optics as well as Hubble Space Telescope imagery of Ceres both show evidence of smaller-scale surface features [7,8].

The visible and near-infrared (0.4–2.5  $\mu\text{m}$ ) spectral region on Ceres is relatively featureless, and has not been terribly useful for rotational studies as a result (in contrast to Vesta). However, the 3- $\mu\text{m}$  region is home to a number of identifiable absorptions in Ceres' spectrum. Carbonates near 3.3 and 3.9  $\mu\text{m}$  were recently detected [9], while an enigmatic feature near 3.05  $\mu\text{m}$  has been variously assigned to water ice,  $\text{NH}_4^+$ -bearing clays, and Fe-rich clays [9-11]. Thermal emission is also observable at these wavelengths for Ceres. All told, these factors make the 2–4- $\mu\text{m}$  region a promising one for studying or constraining spectral variation on Ceres. With Ceres the focus of increasing interest due to the launch of the Dawn mission, we undertook such a study.

**Observations:** We obtained spectra of Ceres using the NASA Infrared Telescope Facility (IRTF) on 17 and 18 May 2005. We used SpeX, the facility spectrograph, in long-wave cross-dispersed (LXD) mode, covering 1.9–4.1  $\mu\text{m}$  [12].

Ceres was observed throughout an entire rotation when pooling the two nights' data, with some overlap in sub-Earth longitudes between nights. The longitude system for Ceres used in this work is based on recent HST observations [7,13], which define a prime meridian and use a right-handed system (increasing eastward). The 685 original images were grouped into bins of 8-12 images, resulting in 55 different "observations", with separations ranging from 3-20°.

**Reductions:** The data were reduced using Spextool, an IDL-based code supplied by the IRTF [14]. Reduced spectra were further corrected for atmospheric contributions using an ATRAN model atmos-

phere, as used by several earlier workers [9]. The spectra were corrected for thermal emission by using a modified version of the Standard Thermal Model (STM), treating the albedo as an unknown. Technically speaking, the beaming parameter ( $\eta$ ) is also unknown, but it is not expected to change over the short timescale of our observations. Therefore we fix  $\eta$  at 0.89, and consider the relative variation of the albedo. Further details of data collection and reduction are found in [9], where an average of the entire dataset were presented.

**Results:** Selected reflectance ratios are shown in Figures 1 and 2 below. Figure 1 shows the variation (or non-variation as the case may be) of the 2.95- $\mu\text{m}$  and 3.05- $\mu\text{m}$  reflectances compared to the continuum at 2.50  $\mu\text{m}$  and to each other. Solid lines show the average values for these ratios on Ceres. The 2.95- $\mu\text{m}$  reflectance does not appear to change appreciably with rotation, while the 3.05- $\mu\text{m}$  band shows possible hemispheric-level variation, albeit only at the 1- $\sigma$  level.

Figure 2 shows the co-variation of the 3.05- and 3.35- $\mu\text{m}$  reflectances, indicating the co-occurrence of Fe- or  $\text{NH}_4^+$ -rich clays and carbonates. Although the error bars are relatively large, there are some hints that the clays and carbonates can be found in slightly differing relative concentrations, even on regional scales. However, the variation seen is also consistent with scatter around a mean value. Even if this variation is real, the overall ratio is relatively stable across Ceres' surface.

Figure 3 shows the preliminary albedo variation with rotation, derived from the emitted/reflected ratio at 4.05  $\mu\text{m}$ . Again, the specific average value here is dependent upon our choice of  $\eta$ , but the relative variation around the mean is independent of  $\eta$ . The variation in albedo spans roughly 10%, which is consistent with the scatter among nearby points. The gray band on Figure 3 shows the mean  $\pm 1\sigma$  error bars for the model albedo.

**Implications:** While the values for the albedos and reflectance ratios are still somewhat preliminary, we can already infer the following:

1. Ceres' albedo shows no systematic variation with longitude greater than a few percent at the most. This contrasts with a  $\sim 30\%$  variation in albedo on Vesta on a hemispheric scale. This is also con-

sistent with previous work at shorter wavelengths [7,15].

2. Hydrated minerals and carbonates are found across Ceres' surface, in roughly constant amounts, suggesting pervasive aqueous alteration rather than patchy, more limited alteration.
3. The relatively flat carbonate vs. hydrated mineral trend is consistent with hydrated minerals and carbonates forming together. If instead they had formed separately, they might be expected to have uncorrelated concentrations.

Further discussion, and a comparison with the HST and AO maps of Ceres will be presented.

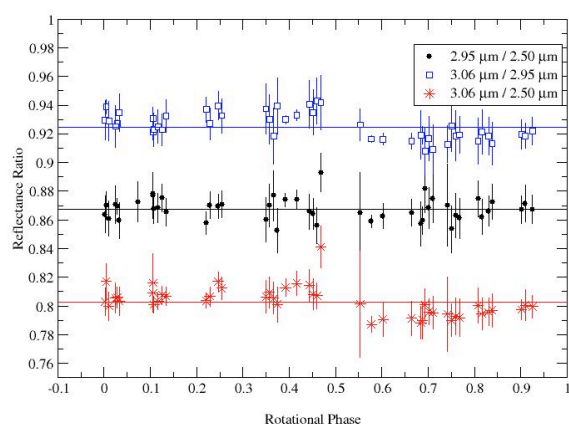


Figure 1: The band depths for hydrated mineral absorptions are fairly constant across Ceres' surface on large scales. The symbols represent different wavelengths within the broad 3- $\mu$ m absorption, with 3.06  $\mu$ m near the band minimum for Fe-rich or  $\text{NH}_4^+$ -bearing clays [9,11]. Solid lines represent the mean for each reflectance ratio. The prime meridian for Ceres found in [7] is at phase 0.85 on this plot.

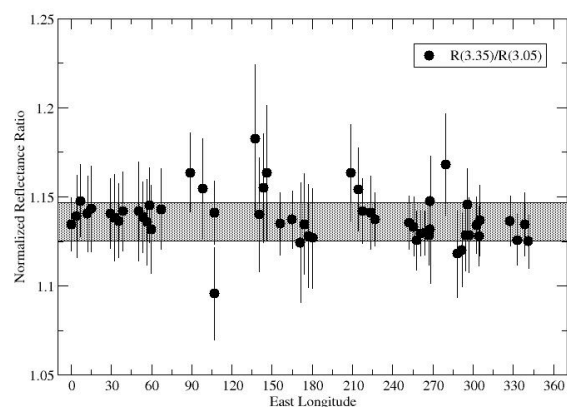


Figure 2: The 3.35  $\mu$ m carbonate band and 3.05  $\mu$ m Fe-rich/ $\text{NH}_4^+$  clay band are found in similar relative

abundances across Ceres' surface. The mean  $\pm 1\sigma$  values for the 3.35- $\mu$ m to 3.05- $\mu$ m reflectance ratio are represented by the gray band. This shows no systematic variation greater than the scatter of the points, though there is perhaps a hint that the 300°-0° region might have a higher ratio (and thus less carbonate relative to the clay) than the 45°-105° region.

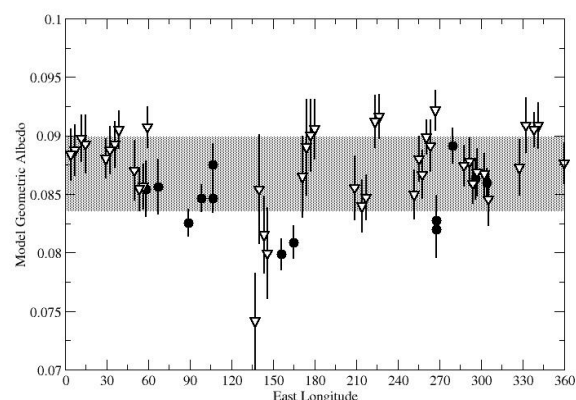


Figure 3: The model geometric albedo, assuming an  $\eta$  of 0.89, also shows no systematic variation with longitude. The albedo is generated using the flux at 4.05  $\mu$ m and a modified version of the Standard Thermal Model. The gray band represents the mean  $\pm 1\sigma$  value for the model albedo. The low points near longitude 150-180° are affected by scatter in the spectra near 4.05  $\mu$ m rather than true measures of Ceres' albedo at those longitudes. The overall variation is much less than is seen for Vesta. The open symbols are data from 17 May, the closed symbols from 18 May.

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