PHASE ANGLE EFFECTS ON 3-μm ABSORPTION BAND ON CERES: IMPLICATIONS FOR DAWN .

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Introduction: The Dawn spacecraft will rendezvous the largest asteroid in the Main Belt, 1 Ceres, in the spring of 2015 [1]. One of the Dawn mission's primary science objectives is to determine the origin and evolution of Ceres by mapping the mineralogical composition across its surface. Ceres is thought to be a water-rich object that has experienced significant aqueous processing [2, 3,4].

Absorption features in spectra around 3.0 μm are particularly diagnostic of aqueous alterations. These absorptions are likely due to hydroxyl- and/or water-bearing materials [e.g., 4], but could also have a contribution from surficial OH implanted from solar wind [5] or exogenic sources like those seen on Vesta. On the basis of the 3.0-μm absorption feature, [4] discovered that the surface composition of Ceres is not as unique as once thought. [4] found that asteroids 10 Hygiea and 324 Bamberga both have similar 3.0 μm band center (at 3.05 μm) and shape as asteroid Ceres, suggesting that Ceres's surface mineralogy is not unique. [4] Grouped Ceres, Hygiea, and Bamberga in one group, on the basis of the 3.0 μm band center, and called it Ceres-like group. In addition to Ceres-like group, [4] discovered another group, Europa-like, which has similar band shape as Ceres-like group, but it has a 3-μm band center at 3.14 μm, possibly attributed to phyllosilicates that allow interlayer H_2O (along with OH), such as montmorillonite.

Here, we analyzed long wavelength cross-dispersed (LXD) spectra of Ceres, measured at different phase angles ranging from 0.7° to 21°. Our hypothesis is that phase angle variation of the observed asteroids does not affect the 3 μm band center, and hence does not affect the mineralogical interpretation of spectral features and diversity in asteroids, including Ceres. These results will have some implications on the interpretation of ground-based and Dawn spacecraft spectra of Ceres.

Methodology:

Observational Techniques. Ceres spectra were collected between September 1, 2011 and December 18, 2012 at various phase angles ranging from 0.7 to 21°, using both the prism (0.8-2.5 μm) and the LXD (1.9-4.1 μm) modes of the SpeX spectrograph/imager at the NASA Infrared Telescope Facility (IRTF) [6]. This investigation also includes near-infrared spectra (NIR: ~0.4-2.5 μm) as well as previously published visible spectra (~0.4-0.93 μm) from the second phase of the Small Main Belt Asteroid Spectroscopic Survey (SMASS II) [7], to help provide a deeper understanding of the surface compositions of Ceres-like group.

Data reduction. We used standard NIR reduction techniques in order to reduce both prism and LXD spectra. The data were reduced using the IDL (Interactive Data Language)-based spectral reduction tool Spextool (v3.4) [8] in combination with some custom IDL routines [4]. The reduction techniques include subtracting the asteroid/star spectrum at beam position A from spectrum at beam position B of the telescope in order to remove the background sky. Asteroid and standard star spectra were extracted by summing the flux at each channel within 8 pixels wide aperture. Asteroid spectra were shifted to sub-pixel accuracy to align with the calibration star spectra and then were divided by appropriate calibrating star spectra at the same airmass (±0.05) to remove telluric water vapor absorption features.

Thermal Excess Removal. The measured Ceres LXD spectra showed a steep increase of apparent reflectance longward of ~3.6 μm due to thermal radiation from the asteroid's surface. We removed the thermal excess in Ceres' spectra following the methodology described in [4].

Calculation of Band Center. Following a standard technique described by [9], absorption features in the 3 μm region were isolated, and each was divided by a straight-line continuum in wavelength space. The continuum was determined by a maxima at 2.85-2.90 μm and 3.00-3.10 μm. The band center was determined by applying a sixth-order polynomial fit to the central part of the feature. An average of three measurements, determined by varying the positions of band maxima, was used for each band center calculation.

Results:

Figure 1 shows the measured LXD spectra of Ceres in September 2011, October 2011, September 2012, and December 2012 at phase angles of 8°, 11°, 21°, and 0.7°, respectively. The dashed line at 3.05 μm represents the band center calculated for Ceres spectra that were measured by [10] and Ceres-like group spectra (Hygiea and Bamberga) measured by [4]. Table 2 shows the calculated band centers of the 3-μm band of Ceres, Hygiea, and Bamberga (Ceres-like group) observed at different phase angles ranging from 0.7 to 21°.

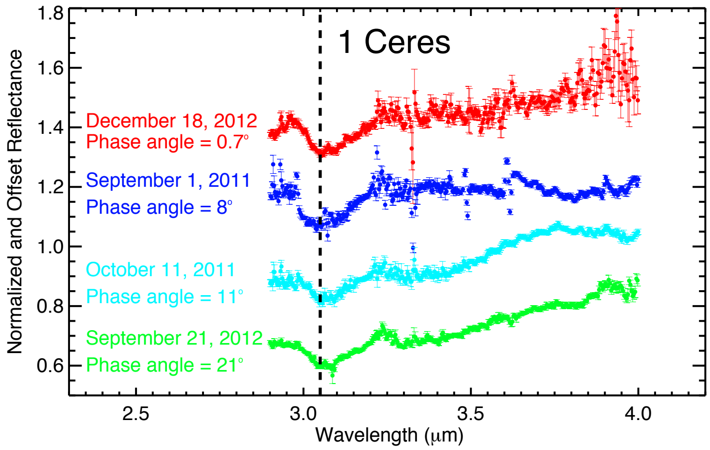

Figure 1. IRTF LXD Ceres spectra measured at different dates and phase angles (0.7 to 21°).

	Phase angle (deg)	3-μm band center (μm)
Ceres- Dec 18, 2012	0.7	3.08±0.01
Ceres- Sept 1, 2011	8	3.07±0.01
Ceres- Oct 11, 2011	11	3.07±0.01
Ceres- Sept 21, 2012	21	3.08±0.01
[1]Ceres- May, 2005	5	3.05
[2]Hygiea- April, 2010	18	3.05±0.01
[2]Bamberga-May, 2011	13	3.05±0.01

Table 1. The calculated 3-μm band centers in spectra of Ceres and Ceres-like group (Hygiea and Bamberga) observed at different phase angles ranging from 0.7 to 21°. [1]Spectra were measured and analyzed by [10]. [2]Spectra were measured and analyzed by [4].

Discussion:

In this study, we analyzed LXD spectra of Ceres that were measured at different phase angles ranging from 0.7° to 21°. We did not find any change of the 3-μm band center with phase angle, all our calculated band centers are within the uncertainties. However, our calculated 3-μm band centers (3.07-3.08 μm) of Ceres are slightly different than the 3-μm band centers calculated by [10] for Ceres (3.05 μm) and by [4] for Ceres-like group (3.05 μm). The small variation in the band center could be due to the different observation and analysis techniques used in this study and the techniques used by [10] and [4].

Additionally, the lack of a significant change in the 3-μm band center in Ceres and Ceres-like group could be due to the small range of the phase angles these asteroids were observed at (0.7° -21°). Because most Main Belt asteroids, including Vesta and Ceres, have a maximum excursion in solar phase angle that is limited to ~25°, we expect no effect of the phase angle on the 3-μm band center for ground-based observations. However, for spectra acquired by Dawn spacecraft, at a wider phase angle range (~25° to 155° for Ceres), photometric correction must be applied to these spectra in order to be able to interpret their spectral features.

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