FIRST KECK ADAPTIVE OPTICS GLOBAL INFRARED (2.2-4.1 µm) SPECTRAL MAP OF CERES: RESULTS AND A REVIEW OF KEY QUESTIONS IN ADVANCE OF DAWN'S EXPLORATION.

B. L. Ehlmann[1,2] and M. E. Brown[1], [1]Division of Geological and Planetary Science, California Institute of Technology, Pasadena, CA, USA (ehlmann@caltech.edu). [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA..

Introduction: We have acquired Keck/NIRSPEC disk-resolved infrared observations of Ceres over three half-nights in June 2014 with global coverage. This is the first global mapping of spectral units in the shortwave infrared (2.2-4.1 µm). These data complement and supplement existing shortwave infrared data sources for Ceres and provide an opportunity to review key findings and key questions in advance of the exploration of the Dawn spacecraft, in particular its VIR imaging spectrometer [1].

Composition and Spatial Variability of Ceres, Key Knowns and Unknowns: Recently, [2] provided an excellent review of all telescopic datasets from Ceres. Visible/near-infrared (VNIR) spectra show a subtle absorption near 0.6 µm [3, 4] that may be due to magnetite or charge transfer in Fe-bearing phyllosilicates, and Hubble color images show modest spatial variability. Of particular significance are data at SWIR wavelengths which, arguably, reveal the most information on composition. Ceres is anomalous spectrally, distinct even from other hydrated asteroids with ices or hydrated minerals [5]. Ceres' SWIR spectra (and those of two other asteroids, 10 Hygiea, and 324 Bamberga) possess a 3.05-µm absorption feature, uncommon for asteroids, which has been proposed to be an indicator of some or all of

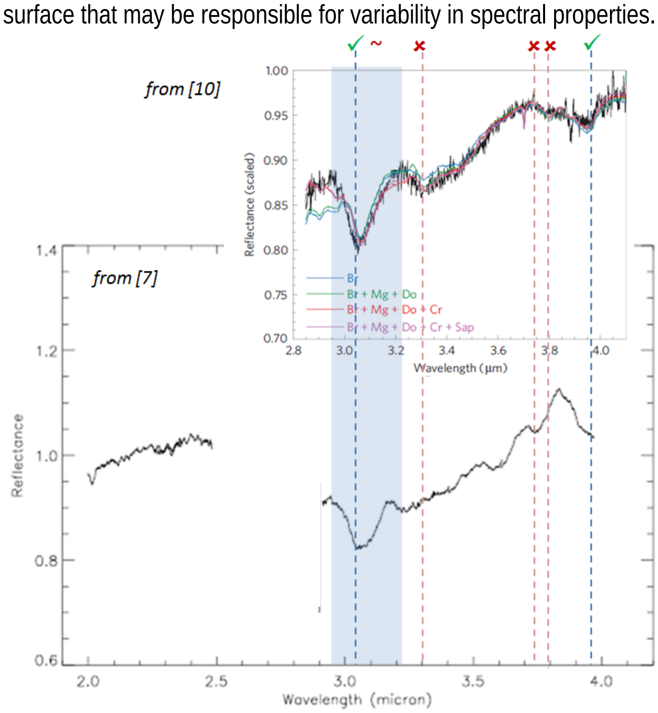
(a) Water ice [6] with irradiated organics [7]
(b) NH4-bearing phyllosilicates (hydrated/hydroxylated aluminosilicates) [8]
(c) Iron-rich serpentine, cronstedtite (a hydroxylated aluminosilicate) [9]
(d) the Mg-hydroxide, brucite [10]

Additionally, faint absorptions near 3.3-3.4 µm have been proposed to be carbonates [9, 10], though organic compounds also have absorptions at these wavelengths.

Whether the hydration signature of Ceres is due to primitive early solar system materials at the surface (carbonaceous chondrite-like), heterogeneous patches of ice, hydrated minerals of various proposed compositions, or a thin atmosphere remains a subject of intense debate. The answer is important for understanding the history experienced by this body, its chemistry, and its bulk water content. For example, if the Ceres surface is comprised of a serpentine-carbonate-brucite assemblages found as large, regional-scale rocky units, this would imply hydrous crust that formed in the interior by hydrothermal/metamorphic silicate-water chemical reactions but rose to the surface in diapirs. The buoyancy is driven by density contrast with anhydrous silicates; heterogeneities in spatial distribution should be observed in this scenario. In contrast, Fe,Mg-phyllosilicates like smectite clays and some serpentines are found in undifferentiated carbonaceous chondrite material. If found in the walls of large impact basins, i.e. at depth, this would imply Ceres did not fully melt. If, on the other hand, the OH/H_2O signature observed telescopically is instead due to ice and organics, this might imply a later delivery process, with more material collecting at the colder poles.

The essential measurements required to distinguish between these compositional possibilities are high

Figure 1. Prior telescopic SWIR observations show similar spectra with some subtle differences that influence the interpretation of the data, including differences in the width of the 3.05-µm feature (shaded gray) and the presence/absence of weaker absotpions from 3.2-3.9 µm. We will compare our NIRSPEC dataset with those from [7, 10], including exploration for spatial heteorgeneties across Ceres' surface that may be responsible for variability in spectral properties.



spectral and spatial resolution IR data that allow resolving absorption center positions, band shapes, and band widths with high confidence and mapping their spatial locations.

Methods: To search for heterogeneities with latitude and longitude, observations of Ceres were obtained over three consecutive half-nights using NIRSPEC [11]. For each observation, approximately 12° of Ceres was imaged, in three separate wavelength ranges, collectively extending from 2.25-4.16 µm. Because of continual rotation, a slightly different portion of the planet was in view for each wavelength range. We chose nearby stars for calibration. Initial data reduction was performed using routines that subtract adjacent pairs of images, correct for the curvature in the spatial and spectral dimensions of the spectrograph, fit and subtract residual line emission, and optimally extract the remaining spectrum.

Results & Review: Now with >3 independent SWIR spectroscopic measurements of Ceres, including our NIRSPEC spatially resolved data, we will explore to what extent the Ceres' spectral properties are consistent across instruments, acquisition dates, and subsets of the Ceres surface targeted for study (e.g., Fig. 1), searching for latitudinal and longitudinal spectral variability. We have observed some initial spatial variability between the brightness at Ceres' north and south poles at long wavelengths (3.7-4.0 µm) (Fig 2). This may be due to a temperature asymmetry (cause unknown) or a compositional difference. We are refining atmospheric and thermal corrections to quantify these effects and will present fully calibrated spectra.

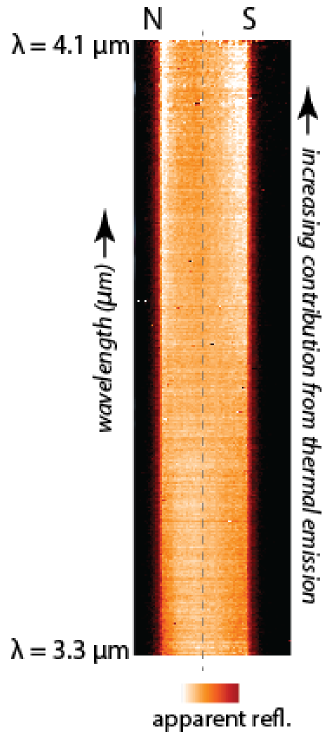


Figure 2. Image data from the NIRSPEC spectrograph (x: cross-section across Ceres, y: wavelength) show an asymmetry in brightness with less incident radiation from the south pole of Ceres. This may be due to a decrease in the contribution to the spectrum from thermal emission (lower temperatures at one pole) or a difference in surface composition.

References: [1] DeSanctis et al., *Space Sci. Rev.* [2] Rivkin et al., 2011, *Space Sci. Review* [3] Vilas et al., 1993; 1994, *Icarus* [4] Fornasier et al., 1999, *Astron. Astrophys. Suppl* [5] Takir & Emery, 2012, *Icarus* [6] Lebofsky et al., 1981, *Icarus* [7] Vernazza et al., 2005, *Astron. Astrophys.* [8] King et al., 1992, *Science* [9] Rivkin et al., 2006, *Icarus.* [10] Milliken & Rivkin, 2009, *Nat. Geosci.* [11] McLean et al., 1998, *Astron. Teles. & Instr., Intl Soc. Optics & Photonics*