A BAYESIAN APPROACH TO DERIVING CERES SURFACE COMPOSITION FROM DAWN VIR DATA: INITIAL QUANTIFICATION OF BRIGHT SPOT AND TYPICAL DARK MATERIAL PHASES WITH THIS METHOD. H. Kurokawa[1], B.L. Ehlmann[2,3], E. Ammannito[4], M.C. De Sanctis[5], M. Lapotre[6], T. Usui[1], N.T. Stein[2], T. Prettyman[7], A. Raponi[5], M. Ciarniello[5], [1]ELSI, Tokyo Tech; [2]Caltech-GPS; [3]JPL/Caltech; [4]ASI, Rome [5]IAPS-INAF, Rome; [6]Harvard University; [7]PSI

Introduction: Infrared spectroscopic observations of Ceres from Dawn/VIR have shown that its dark surface contains Mg phyllosilicates, ammonium-bearing phases, Mg/Ca carbonates, and dark materials, most likely organic carbon or magnetite [1-4]. The high spatial and spectral resolution VIR data also permit study of the composition of distinctive bright spots associated with impact craters [e.g., 5-6], which are enriched in Na carbonates of varied hydration states and NH_4-salts, related to geologically recent brines [e.g., 7-8].

Determining quantitatively the mineral assemblages of the bright spots and dark materials is important to understanding the pH, fO_2, and geochemical conditions of aqueous alteration on Ceres. Understanding the full range of permitted compositions is important for evaluation of geochemical models of aqueous alteration and thus scenarios for Ceres' evolution. The current VIR approach robustly identifies phases based on absorption band locations. The amount of a given material type present is currently constrained by "best-fits" of spectra with Hapke models using optical constants from terrestrial libraries [3, 4, 7, 8]. Potential improvements to the existing state-of-the-art include use of NH_4-phyllosilicate optical constants of Fe/Mg phases suited to carbonaceous chondrites, constraining upper bounds on permitted amounts of hypothesized but undetected phases (e.g., brucite, sulfates), and determining statistically rigorous error bars on quantification of material types present.

Methods: We are beginning to model VIR data using (i) a recently-developed Bayesian method for quantifying phase abundances from infrared spectral data [9] and (ii) addition of Ceres-appropriate optical constants based on our recent labwork ammoniating phyllosilicates [10]. We report on initial results from (i) here. As with prior work [3,4,7,8], we utilize the Hapke unmixing model, which assumes the single-scattering albedo spectrum of a surface is the sum of the single-scattering albedo (SSA) spectra of the material types comprising the surface, weighted by their cross sectional areas and proportional to abundance. Inputs are SSAs of the end member material types or their optical constants (n,k) as well as abundances range (0-100%) and grain sizes (10 μm-1 mm). In this abstract, we show initial model results using SSAs as input because [9] and our pilot tests showed low sensitivity to grain size in this grain size range.

The novel part of our approach, the Bayesian Markov Chain Monte Carlo implementation of the Hapke

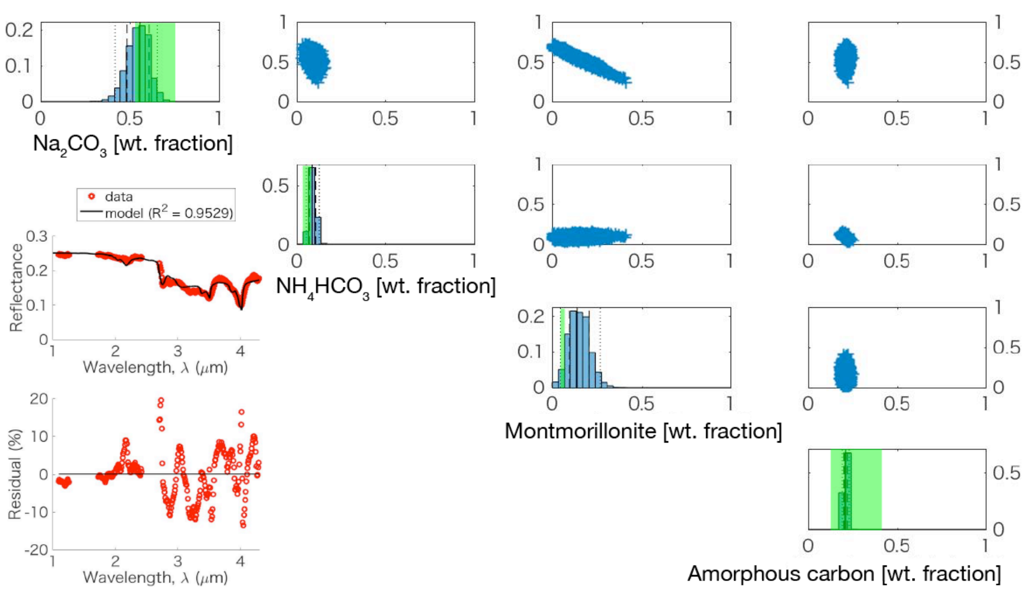

Figure 1. Bayesian MCMC radiative transfer modeling results for the composition of the Occator bright spot for one suite of 4 end members with model reflectance (black) compared to Dawn VIR data (red). PDFs of the abundances (blue) compared to the values from [7] (green) show that our approach allows characterization of the range of compositions that can fit the data. Non-diagonal abundance plots show the correlations (or lack thereof) between endmembers in the acceptable solutions.

model refers to the method used to sample the posterior probability distribution function (PDF), i.e. the probability of a given solution. The PDF of the observation is simulated by using the Metropolis algorithm to draw random sample models whose density is proportional to the posterior PDF. For multimodal posterior PDFs, it may take a long time for the random walk to move from one high-probability region to another. Thus, to increase MCMC sampling efficiency, we use algorithms adapted from the seismological literature [see 9 for method details].

Initial Results: *Bright spots.* Modeling of the largest Occator bright spot with the same end member data as [7] shows that Na carbonates dominate, with a mean around 54±12 wt. % Na carbonate (Figure 1). Some NH_4-salt is required, but the abundance is small and constrained by the fact its inclusion produces a ~3.1-µm absorption that is not observed in the Dawn/VIR data (thus producing a model misfit). Figure 1 shows the results for NH_4HCO_3 and similar values were obtained for NH_4Cl. Significantly, about 20 wt. % of the surface is Ceres dark material, modeled here as organic carbon (IOM from Murchison meteorite as in [7]). In general, these results agree well with [7].

Dark materials. Modeling of the Occator dark floor with the same end member data as [3] shows the dominance of dark materials, here modeled by organic carbon, with a mean around 84±7.3 wt. % (Figure 2). Figure 2 shows that small amounts of NH_4-montmorillonite, antigorite, and Mg-carbonate are allowed to coexist. While the VIR dataset used in Figure 2 is not exactly the same with those used in [3], our results agree with [3].

We performed a sensitivity study with dark materials and found that the spectral slope in the <2.0 µm region is important in dictating the fit. Adding magnetite (20±20 wt. %), which has been proposed as a possible dark material on Ceres, as the fifth end member improved the fit in this region. Even in this case, our model required amorphous carbon as the major component of dark materials (70±17 wt. %), because the reflectance of pure magnetite is too high to reproduce overall darkness of Ceres surface.

Future Work: We will conduct sensitivity tests to determine the robustness of model results with optical constants of the same phase derived from different endmembers, establish upper abundance bounds for other phases in multi-component mixtures, and consider different dark materials. For the Ceres dark surface, we will extend the results of [3-4] by substituting optical constants from [10] with Fe/Mg NH_4 phyllosilicates and re-executing these analyses. We will compare quantitative constraints on mineralogy from VIR with elemental abundance estimates from GRaND [11].

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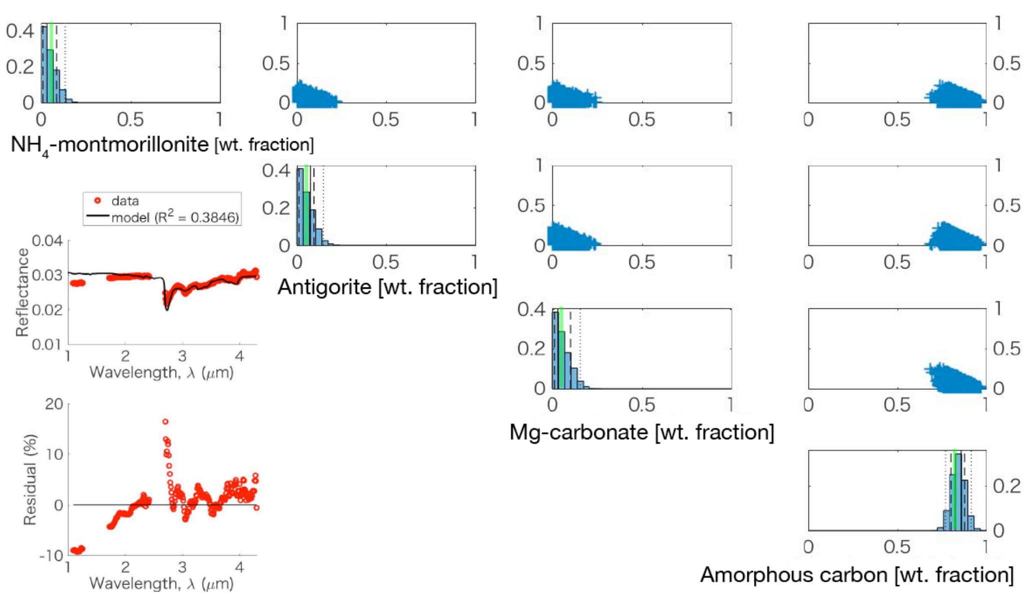

Figure 2. Bayesian MCMC radiative transfer modeling results for the composition of the dark floor for one suite of 4 end members with colors as in Figure 1.