ELEMENTAL COMPOSITION OF CERES BY DAWN'S GAMMA RAY AND NEUTRON DETECTOR.
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Introduction: In December 2015, the Dawn spacecraft entered low altitude mapping orbit (LAMO) around Ceres – a circular, polar orbit with a mean altitude of 0.8 Ceres body radii, about the same relative altitude as Vesta LAMO. By year's end, Dawn's Gamma Ray and Neutron Detector (GRaND) [1] accumulated two weeks of mapping data, with regional-scale resolution and full global coverage. A preliminary evaluation of this data set is summarized here. As with Vesta encounter, the timing of LAMO allows our first results to be reported at LPSC. By March, GRaND will have accumulated sufficient data for a detailed analysis of the elemental composition of Ceres' regolith, which can be compared with Vesta, Dawn's igneous end-member [2].

GRaND expectations: Gamma ray spectra and neutron counting data acquired by Dawn at Vesta were analyzed to determine the global distribution of H, Fe, and other elemental signatures [3-8]. Measurements of Fe/O, Fe/Si, and K/Th confirmed the connection between Vesta and the howardite, eucrite, and diogenite (HED) meteorites [3,9]. Vesta's basaltic regolith contains 100s of ppm exogenic H, likely delivered by carbonaceous chondrite (CC) impactors [3].

In contrast, Ceres' upper regolith is rich in hydrated minerals [10] and may contain water ice. Ceres' intermediate density between ice and rock indicates a volatile-rich interior [11]. Internal heating by radioelements may have driven aqueous alteration and differentiation to form a rocky core and volatile-rich outer shell freezing over a liquid layer [e.g. 12, 13]. Crustal overturn, impacts, and cryovolcanism may have delivered volatiles and products of aqueous alteration to the surface.

Ceres' surface is sufficiently cold that water ice can survive at high latitudes for >1 Ga within the decimeter depths sensed by GRaND [e.g. 14,15]. Given Ceres' current low obliquity, water ice and other volatiles may be cold-trapped in permanently shadowed regions near the poles [15]. Ice stability models predict a simple two-layer structure for Ceres' regolith (lag deposit covering icy soil).

GRaND measurements can be compared with other remote sensing data sets, geochemical models and H-rich CCs, which are compositional analogs for Ceres [16]. Orbital measurements by Dawn's Visible and

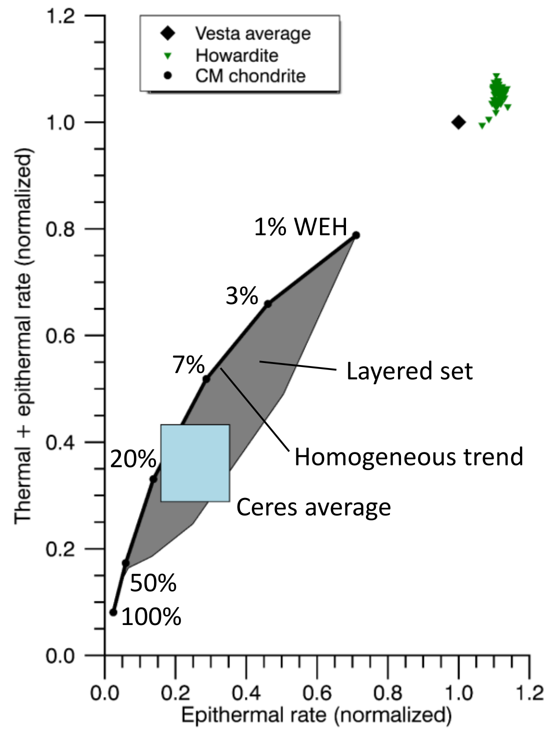

Figure 1. Globally averaged neutron counting rates measured by GRaND show that Ceres' regolith is H-rich. Ceres measurements(blue box) are compared to Vesta and model compositions: H-free howardites and a CM chondrite with variable amounts of H. Hydrogen concentration is expressed as wt% water-equivalent hydrogen (WEH). Neutron counts decrease monotonically with increasing WEH following a specific trend line for homogeneous surfaces (1% to 100% WEH shown) . Two-layer surfaces fall within the gray area. The measurements overlap homogeneous and layered surfaces.

near-InfraRed (VIR) spectrometer show that Ceres' surface contains ammoniated phyllosilicates along with other hydrous minerals, opaques, and carbonates [10]. Ammonium is not expected to contribute significantly to the H content of the regolith. In the absence of water ice, H is primarily in the form of OH and H_2O in phyllosilicates. Measurements of other elements such as Fe and Si by GRaND can help determine whether alteration products are present. Elements diagnostic of hydrothermal activity (Cl, S, and K) [17] may be detectable by

GRaND if present in high concentrations within broad surface regions.

The objectives for GRaND at Ceres are to determine the concentration of H and characterize H layering within the topmost meter of Ceres' regolith; provide information needed to determine how H is partitioned between water ice and hydrous mineral phases; and determine the H-free elemental composition of the regolith. Elemental data will be combined with other remote sensing observations to constrain regolith properties and the interior structure and chemistry of Ceres.

Preliminary results: Analyses of data acquired in LAMO demonstrate that Ceres' regolith is rich in H in comparison to Vesta (e.g. Fig. 1). Measurements shown in Fig. 1 are by GRaND's +Z phoswich scintillator, which faces Ceres during science data acquisition. Neutron measurements are sensitive to H concentration and layering; however, the thermal + epithermal (TPE) rate (^{6}Li(n,α) reaction rate in Li-loaded glass) is also sensitive to the absorption of low-energy neutrons within the regolith. Consequently, the analysis of layering depends on model composition, especially the concentration of strong neutron absorbers Fe and Cl. The sensitivity of our results to H-free regolith composition will be tested using geochemical models and meteorite analogs. Other GRaND measurements (e.g. H, Fe, fast neutrons, and high-energy gamma rays) are sensitive to layering and will be included in our analysis.

Differences in gamma ray spectra measured by the bismuth germanate scintillator at Ceres and Vesta are qualitatively consistent with a CC-like composition for Ceres. At Ceres, increased intensity of the 2.2 MeV peak (neutron capture by H) and strong suppression of the gamma continuum supports relatively high concentrations of H within Ceres' regolith. Measurements of the Fe 7.6 MeV capture gamma ray in combination with other signatures suggest that Ceres' regolith is layered.

Neutron and gamma ray counts are much lower near the poles than at the equator (e.g. Fig. 2), consistent with increased concentrations of H within the topmost meter of the regolith at high latitudes. Lower bound estimates of the concentration of H in polar regions (>20% WEH) are higher than the average for CI chondrites [18]. Excess H at high latitudes is probably in the form of near-surface water ice as anticipated by ice stability models; Changes in the hydration state of phyllosilicates and hydrated salt minerals with temperature [e.g. 19] may also contribute to observed spatial variations.

Conclusion: Preliminary results indicate that Ceres' regolith has an H-rich, CC-like composition, with water ice likely present near the surface at high latitudes. Additional accumulation time and analysis is needed to characterize H layering, map the concentration of major elements, and identify products of aqueous alteration. With more data, it may be possible to quantify or bound the concentration of additional elements, including C, Mg, S, Cl, K, and Ni. We will report results of the analysis and implications for Ceres formation and evolution.

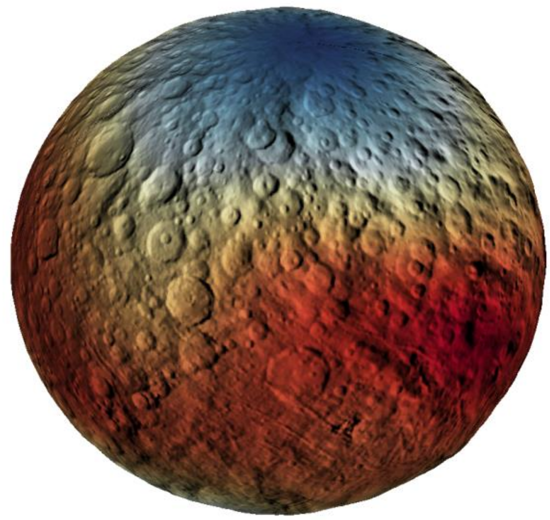

Figure 2. Smoothed map of thermal + epithermal counting rates (blue-yellow-red) measured by GRaND's Li-loaded glass scintillator. The map is superimposed on a shape model of Ceres with shaded relief. The model is tipped slightly to show the northern high latitudes. The lowest rates (found at the north pole) are shown in blue. The highest rates (equator) are shown in red. The southern high latitudes (not shown) have a similar appearance.

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