

CERES COMPOSITION BY VIR ON DAWN: HIGHLIGHTS OF THE FIRST YEAR OF OBSERVATION.

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Introduction: The Dawn spacecraft [1] reached Ceres in early 2015, starting an impressive observational campaign. Dawn is equipped with a Visible and Infra-Red Mapping Spectrometer (VIR-MS) [2]. VIR-MS is an imaging spectrometer coupling high spectral and spatial resolution in the VIS (0.25-1- μm) and IR (0.95-5- μm) spectral ranges. VIR acquired data during Approach, Survey, High Altitude Mapping (HAMO) and Low Altitude Mapping (LAMO) orbits. The different phases of the mission provided good coverage of the surface (Approach and Survey) and high spatial resolution data (HAMO and LAMO).

Ceres Surface Composition: Ceres surface has a low albedo, except small localized areas that exhibit unexpectedly bright materials. Since the first approach data, near infrared spectra revealed a dark surface (albedo of 0.035) with moderate temperatures (180-220 K), with strong absorption bands in the 3 micron spectral region (fig.1) [3]. This range includes the 2.6–2.9 μm range of wavelengths precluded from telescopic measurements owing to the atmospheric absorptions. As such, Dawn data provide new constraints on Ceres' surface composition. Near-infrared spectroscopic analyses confirmed previous observation of bands at 3.1, 3.3-3.5, 3.9 micron; in addition VIR clearly identified the band at 2.72 micron. This characteristic narrow feature is distinctive of OH-bearing minerals, while H₂O-bearing phases, show a much broader absorption band that is a poor match for the Ceres spectrum. Water ice does not fit the observed spectrum, consistent with its instability at the maximum surface temperature.

The 3.05–3.1 μm band observed also in the Ceres' ground-based spectra, has been attributed to different phases including water ice, hydrated or NH₄-bearing clays and brucite [4,5,6]. In particular, ammoniated mineral species, including NH₄-bearing annite and NH₄-montmorillonite, show a band near 3.06 μm , could account for this band. The best fit of Ceres' average spectrum over the infrared range is obtained by adding ammoniated phyllosilicates to a dark material (likelly magnetite), antigorite and carbonate [7]. Dif-

ferent ammoniated clays can match the Ceres spectrum, although the specific clay mineral cannot be determined. Similarly, carbonates are always needed in the spectral mixing model, but the specific carbonate mineral is not fully constrained because dolomite, magnesite and calcite produce equivalent matches to the observed Ceres spectrum. These different components, including ammoniated hydrates (which normally are present in the outer solar system) are everywhere across the surface although with different relative abundances [8]. Particularly interesting are the bright materials present in some craters like Occator, Haulani (fig.2) and Oxo that show different proportions of the components of the mixture [8]. However, the distribution of surface units revealed by absorption band depths is not always linked to morphological structures.

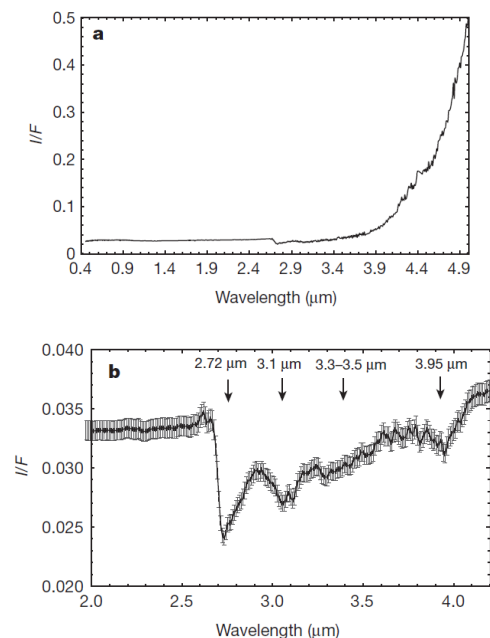


Fig.1 **a**, Average spectrum of Ceres from 0.4 μm to 5 μm . **b**, Expanded thermal-removed average Ceres spectrum in the 2–4.2 μm range. Main bands are indicated by arrows.

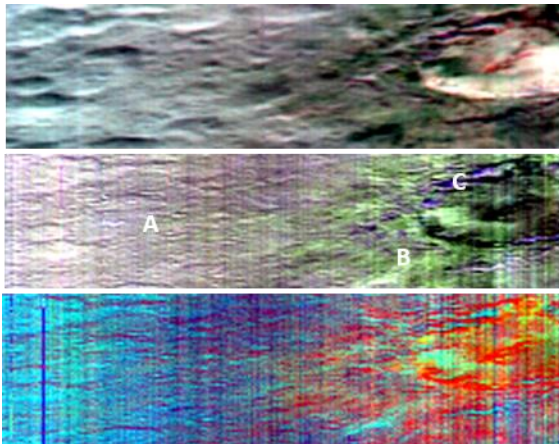


Fig.2 TOP) RGB image of Haulani crater taken during HAMO phase by VIR (R: 2 μ m, G: 3.05 μ m, B: 2.9 μ m. The image is not geographically projected. MIDDLE) RGB VIR image normalized at 2 μ m (R:3.2 μ m, G:3.05 μ m, B:2.9 μ m); BOTTOM) RGB image normalized at 2 μ m (R: 1.7 μ m, G: 2.7 μ m, B:2.9 μ m).

Top: Red represents a continuum, a region with no absorption at 2- μ m. Green (3.05 μ m) represents a region with a weak absorption due to the ammonium ion in a clay mineral. Blue (2.9 μ m) represents the absence of a strong OH absorption in the clay minerals. **Middle:** The ejecta around Haulani crater, shown in green (fig.3), has high values of both 3.2 and 2.9 μ m relative to 3.05 μ m indicating a region relatively depleted of ammoniated-clays. The purple region below the rim of Haulani is relatively enriched in the ammoniated species (fig.3) with respect to other areas. Further from the crater, the distribution of ammoniated OH-bearing species is more homogeneous as represented by light-purple pixels (light-purple spectrum in fig.3). **Bottom:** The reddish region has a higher 1.7/2.0 reflectance that implies a blue slope outside of the OH absorption band complex that further characterizes the ejecta material. The ejecta near the crater have different spectral properties than the terrain further from the crater, suggesting lower clays in the ejecta.

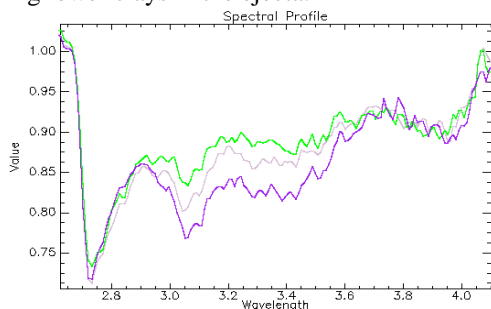


Fig.3. Spectra taken from A,B,C in fig.2 (middle): A- light purple spectrum, B-green spectrum, C-purple spectrum.

Implication: The retrieved composition indicates a pervasive aqueous alteration of the surface. Ceres' low density and the presence of OH-bearing minerals, suggest a high content of water inside the body. Large amount of ice on the surface is unlikely due to the stability of such phase at the Ceres surface temperatures [9]. Ceres seems to have been subject to differentiation and hydrothermal activity, and, according to some models, might host a liquid subsurface layer even today [10]. Geochemical modeling using a carbonaceous chondrites (CM) starting composition can produce the observed Ceres mineralogy. This kind of mixture indicate extensive alteration, also favored on large bodies like Ceres [11].

Ceres' surface enrichment in ammoniated phyllosilicates and relatively low bulk density pose questions on its origin and formation. Ceres has been seen as the prototype of C-type asteroids, which could have formed close to their current locations. However, the presence of ammoniated clays (ammonia ice is extremely volatile) together with the low density, may indicate that Ceres retained more volatiles than objects represented in the meteorite collection, or that it accreted from more volatile-rich material. It is possible that Ceres grew close to its present position by accreting smaller objects, some of which could have drifted inward from larger heliocentric distances where ammonia was stable. Alternatively, Ceres may itself have formed further out in the Solar System, presumably in the trans-Neptunian disk, before being subsequently implanted in the main belt.

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References

- [1] Russell, C.T. et al., *Science*, 336, 684, 2012.
- [2] De Sanctis M.C. et al., *SSR*, doi: 10.1007/s11214-010-9668-5, 2010.
- [3] De Sanctis M.C. et al., *Nature*, 2015, doi:10.1038/nature16172
- [4] Lebofsky et al., *Icarus* 48, 453–459, 1981
- [5] King, T.V.V. et al., *Science* 255, 1551–1553, 1992
- [6] Rivkin, A.S. et al., *Icarus* 185, 563–567, 2006
- [7] Raponi A. et al., *LPSC 2016*
- [8] Ammannito E. et al., *LPSC 2016*
- [9] Formisano M. et al., *MNRAS*, 2015
- [10] Neveu M., Desch S. J., *Geophys. R. Lett.*, 2015.
- [11] McSween et al., *LPSC 2016*