SPECTRAL PROPERTIES OF CERES' BLUISH MATERIAL – COMPARISON WITH TERRESTRIAL IMPACT MELT. K. Stephan[1], R. Jaumann[1], L. A. McFadden[2], D. Haack[1], K. Krohn[1], K. Otto[1], R. Wagner[1], H. Hiesinger[3] and the Dawn Science Team, [1]Institute of Planetary Research, Rutherfordstrasse 2, 12489 Berlin, Germany, [2]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [3]Westfälische Wilhelms-Universität, Münster, Germany (e-mail: Katrin.Stephan@dlr.de).

Introduction: Since NASA's Dawn spacecraft arrived at Ceres in March 2015, its Visible and Infrared Spectrometer (VIR) experiment [1] has shown that the surface composition of Ceres, with a diameter of 945 km, the largest object in the asteroid belt, is dominated by a mixture of ammoniated phyllosilicates, Mg-phyllosilicates, carbonates and a spectrally neutral dark material [2] with the abundance of each individual surface compounds variable across the surface [3]. Locally, also H_2O ice could be detected [4]. The VIR-derived composition, however, does not explain color variations observed in the visible spectral range. Color images returned by Dawn's Framing Camera (FC) [5] show extended regions with a negative (blue) spectral slope [6,7]. We investigated the nature of the bluish material based on the combination of Dawn's imaging and spectral data sets, i.e., the spectral characteristics of the bluish material in combination with its geologic and topographic context, which also may offer implications for the existence of blue-sloped material on other planetary bodies as well.

Dawn Results: The global classification map of the spectral slope between the FC filters F8 (438 nm) and F3 (749 nm) (Fig. 1) shows distinct patches of bluish material distributed across Ceres's surface. The ratio values vary between <1 (red slope) and >1 (blue slope). The corresponding VIR average spectra, which have been measured for each major class (Fig. 2), show a reflectance maximum around 0.5 µm with the spectral continuum decreasing toward the UV as well as into the NIR up to 2.5 µm in the bluish areas. In contrast, the VIR spectra of the red regions exhibit a less marked reflectance maximum at longer wavelengths (~0.64 µm) and a more or less increasing reflectance toward longer wavelengths. The OH-absorption at 2.73 µm, which is apparent in all Ceres' spectra is generally weak in the blue-sloped regions.

In comparison with the geology/morphology of Ceres, it is clearly evident that the distribution of blue-sloped material is associated with fresh impact craters and their ejecta [6,7], whereas the oldest heavily cratered regions exhibit an reddish spectral signature (Fig. 3). Linear features that cross Ceres's surface for hundreds of kilometers also show a bluish signature (because of the spatial resolution they only appear green in the classification map of Fig. 1), which sometimes appear to be radial to large craters and thus were interpreted to be ejecta material [8].

Interpretation: Thus, bluish material on Ceres represents fresh/un-weathered material that either exists in the subsurface and has been exposed due to impact events or has been formed during the impact processes. Although rare, spectrally blue slopes have been measured on several planetary bodies such as B-type asteroids [9], icy satellites of Jupiter and Saturn [10,11] and some carbon-rich meteorites [12], possibly caused by compositional (contribution of magnetite) and/or physical properties (larger grains or shocked and/or amorphous material) of the surface material (Fig. 3).

Oxo (diameter: 10 km; 42.2°N/359.6°E) is the only impact crater on Ceres, which is characterized by a bluish slope and also shows a partial H_2O-ice signature (Fig. 2). All other impact features are dominated by phyllosilicates and/or carbonates, which mostly show a more reddish spectral signature. However, physical alteration processes due to low-velocity impact events such as heating up to moderate temperatures and melting is expected on Ceres and could explain the observed blue spectral slope. In particular, ultrafine grains and partly amorphous phyllosilicates have been found to form larger agglomerates showing a blue slope [13] and possibly caused by the sticky behavior of impact-induced phyllosilicate dust and/or the amorphization of the ejecta material during the impact process. Space weathering processes (micrometeoritic impacts, temperature changes, mass wasting) cause a reversal of the agglutination process and a recrystallization of the surface material with time resulting in a reddening of the spectral slope.

Especially, melt-rich material usually emplaced during the terminal stages of crater formation conforms to the observed morphology and character of the blue-sloped ejecta deposits, which are often accompanied by lobate shapes indicating melted material flown across the surface [14]. Impact melt can form ponds on a crater's floor but also can occur on the interior crater walls as well as beyond the crater rim. In particular, impacts into phyllosilicates and carbonates, both materials detected on Ceres, which unlike crystalline rocks may be more porous and volatile-rich, are expected to produce more melt than impacts into denser crystalline rocks, and to form aggregates that are ejected from the crater with a plume of expanding volatiles [15]. Material melted and vaporized during the impact event may be ejected to significant distances at high velocities, which could also explain the linear features observed on Ceres [8].

Terrestrial Impact Melt: In order to continue and deepen the evaluation of the possible connection between a bluish spectral slope and the formation of impact melt, we started to measure the spectral properties of terrestrial melt bearing impact breccia originating from 1) Vredefort Dome in South Africa, and 2) Gardnos impact crater in Norway usually showing rounded gneiss inclusions of different sizes in a dense dark gray matrix.

Examples of corresponding spectra acquired by the portable spectroradiometer (PSR+3500) sensitive between 0.35 and 2.5µm are shown in Fig. 3. Contrary to the surrounding rocks or included clasts, but despite different rock compositions, the spectra derived from the extremely fine grained matrix of the measured impact melt samples show a distinct bluish slope as seen on Ceres' and thus apparently support our theory that physical alteration could be one explanation for the bluish material on Ceres.

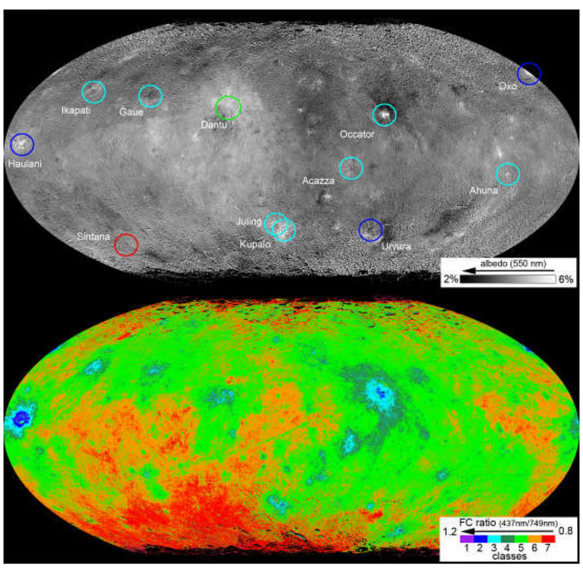

Fig. 1: Classification of the spectral slope derived from the FC ratio image (437nm/749nm).

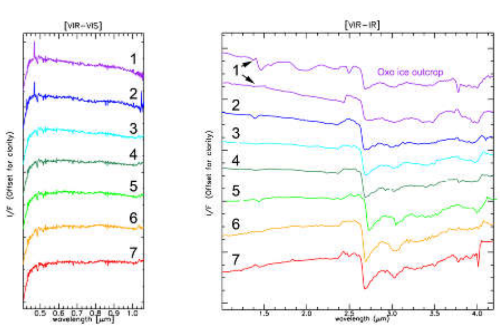

Fig. 2: VIR spectra of the FC ratio classes in Figure 1.

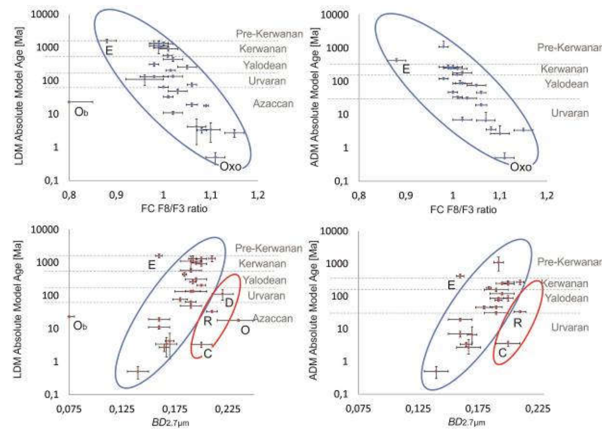

Fig. 3: Comparison of the F8/F3 ratio of Ceres' impact craters and the band depth of the OH absorption at 2.7µm with LDM and ADM model ages.

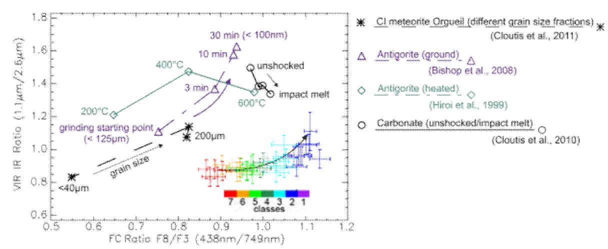

Fig. 4: Comparison of the F8/F3 spectral slope classes of Figure 1 to lab data.

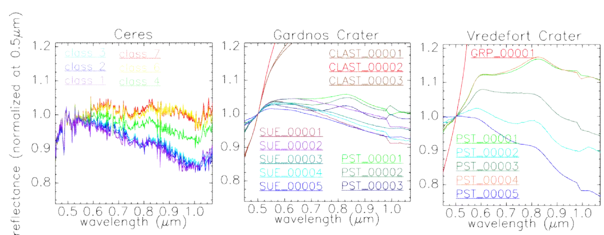

Fig. 5: Comparison of (left) normalized VIR VIS spectra of Fig.2 with PSR spectra of terrestrial impact melt samples from (center) Gardnos crater in Norway and (right) Vredefort crater in South Africa (SUE=Suevite, PST=Pseudotachylite, GRP=Granophyre).

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