THERMAL BEHAVIOR OF BRIGHT SPOTS ON CERES.
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Introduction: At 952 km in mean diameter, the dwarf planet Ceres is the most massive object in the main asteroid belt of our Solar System. Widespread ammoniated phyllosilicates have been detected on Ceres [1] by the Visible and InfraRed (VIR) mapping spectrometer [2] onboard the NASA Dawn spacecraft. The substantial presence of ammonia-bearing minerals and the low bulk density of Ceres represent a challenge for the full understanding of its origin, given its location in the main asteroid belt. In this regard, the analysis carried out by VIR in the region of the infrared spectrum dominated by thermal emission can be fully complementary to the mineralogical analysis conducted at lower wavelengths. VIR hyperspectral images are routinely used, by means of temperature-retrieval algorithms, to compute surface temperatures along with spectral emissivities.

We present temperature maps of some local-scale, bright features of Ceres that were observed by Dawn under different illumination conditions and different local solar times.

Data set and analysis: After the initial *Approach* (January through April 2015) and *Rotational Characterization* campaigns (April through May 2015), the Dawn spacecraft carried out more detailed, visible to near-infrared mapping of the surface of Ceres in *Survey* (June 2015), from an average altitude of 4413 km above mean surface, and *High Altitude Mapping Orbit* (HAMO, August through October 2015), carried out from a 1512-km average height. Dawn finally spiraled down to its 380-km above mean surface *Low Altitude Mapping Orbit* (LAMO), which is also the last phase of the entire mission. Bright terrains with a distinct morphology were identified on the basis of Framing Camera (FC) [3] clear-filter images obtained already in the Approach phase. These bright features were later revealed in greater detail during Survey and HAMO.

Here we calculate surface temperatures of some peculiar bright terrains on the basis of VIR data acquired especially in the Survey and HAMO orbits. In Survey, VIR obtained resolved images with average spatial resolution of ~1.1 km. In the following HAMO phase, VIR acquired hyperspectral images at an average pixel resolution of 0.38 km, re-observing some of the bright terrains (most notably those located in craters Occator and Haulani) in greater detail.

On the dayside of Ceres, the region of the infrared spectrum longward of ~3 μm is increasingly dominated by thermal emission from the surface, which can be used to determine surface temperature by means of temperature-retrieval algorithms. To calculate surface temperatures, we applied a Bayesian approach to nonlinear inversion [4,5] that was extensively applied to the Vesta dataset. In all cases, the minimum retrievable temperature (~180 K) is set by the Noise Equivalent Spectral Radiance (NESR), i.e. the RMS noise of the in-flight measurements expressed in units of spectral radiance. On the other hand, for a given local solar time (LST), the maximum temperature depends on incidence angle and surface properties such as thermal inertia and albedo.

Results: As in the case of Vesta [5], also on Ceres bright terrains may display distinct thermal properties compared to surrounding terrains observed under similar solar illumination. They may show a reduced thermal emission at infrared wavelengths and have either distinct or elusive margins in the temperature images. In infrared data returned by VIR, bright terrains associated with the 34-km crater Haulani (5.7°N, 10.9°E) showed significant thermal contrast already in the Approach phase at coarse spatial resolution (~11 km/px), later fully confirmed in Survey. Indeed, Haulani is the most prominent thermal feature on Ceres, with its bright ejecta and the central part of the crater showing significantly lower temperatures than the rest of the crater and the surrounding terrains (**Fig. 1**). Already in Survey data, Haulani revealed a complex thermal structure at the local scale, with margins of individual cold spots in the thermal image that do not necessarily match features seen at visible to near-infrared wavelengths.

Conversely, the very bright spots associated with 92-km crater Occator (19.8°N, 239.3°E) showed no thermal contrast until VIR images achieved a resolution of a few hundreds of m/px, namely in HAMO (indeed, Occator was missed by VIR in the Survey phase). The thermal structure of Occator is very intriguing, since only the main bright spot located in the center displays a detectable thermal signature (cooler than surroundings), while the secondary bright spots in the eastern side of the crater's floor offer no substantial thermal contrast (**Fig. 2**).

The lower temperatures suggest a higher thermal inertia, i.e. a slower response to changing insolation, which is likely due to a combination of high albedo and increased local density (with a possible contribution from a local change in the thermal conductivity). VIR data acquired in LAMO, as well as a comparison with FC images providing higher resolution and FC-derived geologic maps, will further help the interpretation of the thermal behavior of these and other local-scale structures.

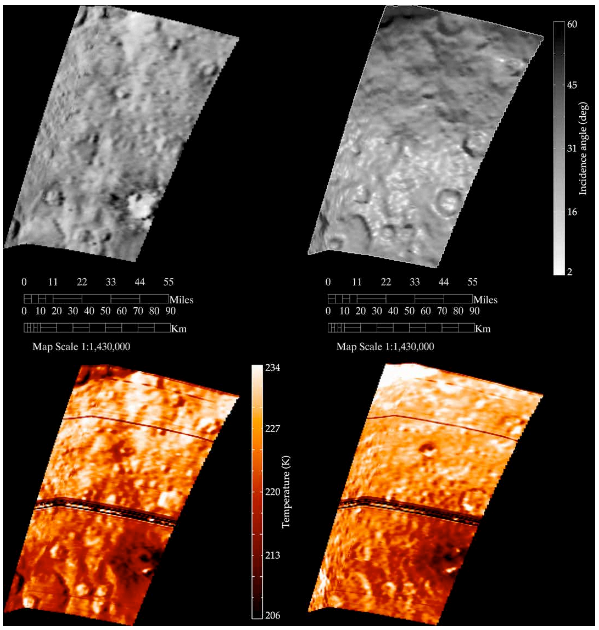

Fig. 1. Equirectangular projection of a portion of Haulani crater, observed by VIR during the Survey phase (1.1 km/px) in the local morning (10.9 LST). A horizontal scale bar accounts for the size of the features observed in the scene. The upper left panel shows the region as seen at the near-infrared wavelength of 1.4 μm (no photometric correction is applied). The upper right panel shows the local solar incidence angle measured from the surface normal to a detailed shape model. Materials illuminated at high incidence angles (dark tones) are generally cooler than materials at low incidence angles (bright tones). The bottom left panel shows a temperature map of the same area, as derived from VIR spectra using the method described in [4] at wavelengths greater than 4.5 μm, where thermal emission becomes dominant. The bottom right panel shows surface temperature corrected for the solar irradiance, i.e. after division by the fourth root of the cosine of the solar incidence angle, which is a quick tool to verify whether the thermal behavior is ascribable to topographic effects (namely shadows in the observed scene) or to inherently warmer or cooler areas. The dark stripes in the temperature maps are artifacts resulting from the original VIR data used for the retrieval. The region of crater Haulani corresponds, in general, to a cold region on the dayside of Ceres, which is likely the result both of high albedo (driven by surface composition) and local density (compactness of the surface material) in this area, compared to the surrounding ones. However, the detailed thermal structure found in Haulani is complex, and the margins of individual cold spots in the thermal image do not necessarily match obvious features in the reflectance map, which deserves further investigation based on VIR data acquired in HAMO and LAMO, and on FC data showing higher pixel resolution.

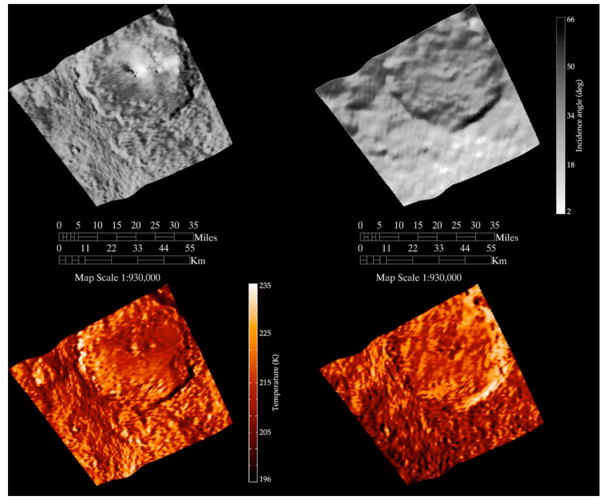

Fig. 2. Equirectangular projection of a portion of Occator crater, observed by VIR during the HAMO phase (0.38 km/px) in the local morning (9.5 h LST), using the same four-panels scheme adopted in **Fig. 1**. A horizontal scale bar accounts for the size of the features observed in the scene. Near the center of the crater, some structures are revealed with thermal contrast not due to the local topography, which correspond to the area of the central (main) bright spot. In contrast, the secondary (smaller) bright spots located in the eastern side of the floor do not show any substantial thermal contrast. The thermal behavior of the bright spots in Occator can be attributed both to their albedo and the compactness of the material they are made of. Daytime surface temperatures in the bright spots are overall incompatible with stable exposure of water ice.

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References: [1] De Sanctis, M.C., et al. (2015). *Nature* 528, 241-244. [2] De Sanctis, M.C., et al. (2010). Space Sci. Rev. 163 (1–4), 329-369. [3] Sierks, H., et al. (2011). Space Sci. Rev. 163 (1–4), 263-327. [4] Keihm, S. et al. (2012). *Icarus* 221, 395-404. [5] Tosi, F., et al. (2014). *Icarus* 240, 36-57.