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Continuum definition for Ceres absorption bands at 3.1, 3.4 and 4.0 µm

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Abstract

The images and hyperspectral data acquired during various Dawn mission phases (e.g. Survey, HAMO and LAMO) allowed identifying regions of different albedo on Ceres surface, where absorption bands located at 3.4 and 4.0 µm can assume different shapes. The 3.1 µm feature is observed on the entire Ceres surface except on *Cerealia Facula*, the brightest spot located on the dome of Occator crater [1]. To perform a mineralogical investigation, absorption bands in reflectance spectra should be properly isolated by removing spectral continuum; hence, parameters as band centers and band depths must be estimated. The problem in the defining the continuum is in the VIR spectral range, which ends at 5.1 µm even though the reliable data, where the thermal contribution is properly removed, stops at 4.2 µm [2]. Band shoulders located at longer wavelengths cannot be estimated. We defined different continua, with the aim to find the most appropriate to isolate the three spectral bands, whatever the region and the spatial resolution of hyperspectral images [3]. The linear continuum seems to be the most suitable definition for our goals. Then, we performed an error evaluation on band depths and band centers introduced by this continuum definition.

1. Introduction

Since March 2015, the *Visible-Infrared Imaging Spectrometer*-VIR [3] and the *Framing Camera*-FC [4] acquired Ceres hyperspectral data and images with increasing resolution, by several mapping orbits performed by NASA Dawn spacecraft (i.e. Survey, HAMO and LAMO phases). Spectrally, the Ceres average surface exhibits absorption bands at about 2.7, 3.1, 3.4 and 4.0 µm, ascribed to phyllosilicates, ammoniated, Calcium- and/or Magnesium-carbonates, respectively [5]. Regions of different equigonal albedo are detected, where the 3.1, 3.4 and 4.0 µm bands can assume slightly dissimilar shapes. Bright areas or bright spots (BS) were identified widespread on Ceres surface: the brightest spot, *Cerealia Facula*, lies on the dome of Occator crater. It is minerally composed by Aluminum-phyllosilicates and high abundance of Sodium-carbonates, as inferred for the longward shift of the 2.7 µm band, the lack of 3.1 µm feature and the strong carbonate absorptions at 3.4 and 4.0 µm. Due to the absence of 3.1 µm band, the left shoulder of 3.4 µm feature is located at shorter wavelengths than the mean Ceres spectrum [1]. To compare parameters of spectra acquired in several phases of mission and from areas with unlike albedo, the same continuum removal method should be applied on the whole VIR dataset. VIR spectral range spans from 0.25 to 5.1 µm, but the reliable and thermally corrected data ends at 4.2 µm [2], making difficult the identification of band shoulders at longer wavelengths. We defined three types of continua (a linear continuum and two that make use of polynomial curves), selecting the one best suited to describe spectra of various regions and properly isolate the 3.1, 3.4 and 4.0 µm absorption bands. Furthermore, for the first time, we estimated the errors on band depths and band centers: this is fundamental to compare spectral parameters of Ceres regions and perform mineralogical and photometric analyses.

2. Description of the method

The spectral continua of 3.1, 3.4 and 4.0 µm features were fitted by using three methods: a linear continuum, a 3rd order polynomial curve (Continuum 1) and a 2nd order polynomial curve (Continuum 2). The linear continuum involves three straight lines, with the endpoints calculated on the shoulders of bands. The left and right shoulders of 3.1 µm band were fitted by a 2nd order polynomial curve in the 2.8-3.0 µm and in the 3.16-3.27 µm range, respectively. The wavelengths corresponding to the maximum fitted value were selected as continuum boundaries. For the 3.4 µm band, the wavelengths corresponding

to local maxima of reflectance level in the 3.05-3.36 µm and in the 3.55-3.68 µm range, respectively, were detected. The boundaries of 4.0 µm band were selected in the ranges 3.55-3.68 µm and 4.05-4.15 µm, respectively. The Continuum 1 was produced by forcing the passage for four local maxima, evaluated in four ranges: 2.85-3.0 µm (R1); 3.17-3.25 µm (R2); 3.65-3.69 µm (R3); 4.0-4.3 µm (R4). The Continuum 2 passes for three local maxima, estimated in the R1, R3 and R4. We applied methods on smoothed spectra acquired during the Survey (altitude 4400 km and spatial resolution ~1.1 km/pixel), HAMO (altitude 1470 km and spatial resolution 360-400 m/pixel) and LAMO (altitude 385 km and spatial resolution 90-110 m/pixel) phases. The selected spectra are representative of dark, intermediate and bright regions and of Cerealia Facula BS. The selection of regions has been performed basing on equigonal albedo values, estimated at 1.2 µm [6].

3. Application of the method

To calculate and compare spectral parameters, the same continuum must be fitted on spectra of any region and removed to properly isolate absorption bands. Continuum 1 properly fits spectra of dark, intermediate and bright regions. The curve is, however, high sensitive to the increasing reflectance over 3.5 µm and therefore, the fitted continuum can assume a slight convexity in the 3.1 and 3.4 µm band and a concavity in the 4.0 µm band. In Occator BS spectra, this effect is highlighted, compromising the correct isolation of bands and the evaluation of spectral parameters. The Continuum 2 is always a good fit for the 4.0 µm band, but it's inappropriate for 3.1 and 3.4 µm bands. The linear continuum can isolate the three absorption bands in any region and predict the lack of 3.1 µm feature in Occator BS spectra. The behavior of three methods on a HAMO spectrum of a bright region, is shown in Figure 1.

4. Error evaluations

A smoothing of reflectance is applied to spectra to reduce the signal fluctuations. The fitted continuum is then removed from the smoothed spectra so that band center and band depth are estimated. The smooth procedure can alter the spectrum and introduce error in the retrieved parameters. Therefore, we removed the fitted continuum from both smoothed and unsmoothed spectra and we estimated the variation of band centers and band depths as uncertainty on the retrieval. The maximum error for the 3.1 and 4.0 µm band centers is well below the VIR spectral resolution, therefore we can assume 0.005 µm as maximum variation, i.e. half the value of VIR spectral sampling. The error associated to the 3.4 µm band center is 2.2%. The highest relative percentage errors (considering dark, intermediate and bright regions) are 3%, 18% and 21% for the 3.1, 3.4 and 4.0 µm band depth, respectively. In Occator BS spectra, the smoothing application slightly change values of carbonates band depths (probably due to the high signal-to-noise ratio), with a maximum error of 2.2% and 1.6% for the 3.4 µm and 4.0 µm feature, respectively.

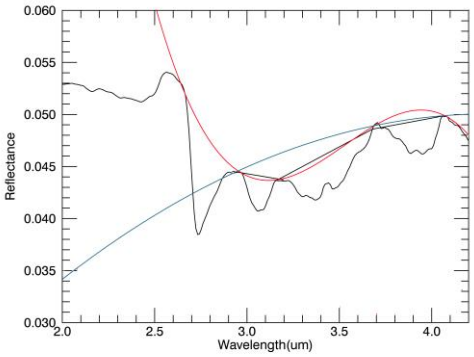

Figure 1: Linear continuum (black line), Continuum 1 (red line) and Continuum 2 (blue line) are superimposed on the spectrum of a bright region acquired in the HAMO phase.

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