Planetary and Space Science 152 (2018) 31–44

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

The on-ground calibration performances of the hyperspectral microscope MicrOmega for the Hayabusa-2 mission

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ARTICLE INFO

Keywords:
Calibration
Hyperspectral imaging
Microscope
MicrOmega
Hayabusa-2

ABSTRACT

The miniaturized near-infrared hyperspectral microscope MicrOmega, on board the MASCOT lander for Hayabusa-2 mission, is designed to perform in situ measurements at the grain scale of the C-type asteroid 1999 JU3 RYUGU. MicrOmega will observe samples with a field of view of a few millimeters with a spatial sampling of 25 μm and acquire near-infrared spectra by illuminating the sample sequentially with different wavelengths from 0.99 to 3.55 μm over two spectral channels with a typical spectral sampling of 20 cm^{-1}. The on-ground calibration of MicrOmega requires a full characterization of the nominal range of operation of the instrument, both spectral (0.99–3.55 μm) and thermal (−40 °C to +40 °C) to derive the radiometric and spectral responses combined into a 4D transfer function to convert raw signal to calibrated reflectance. This specific 4D radiometric reference gives the instrument response according to the pixel location (x,y), the wavelength and the instrument temperature. This paper reports the complex computation of the 4D radiometric reference for the 0.9–2.5 μm channel. In this spectral range, the composition of the grains of a wide variety of minerals with relevance to solar system bodies can be identified through diagnostic spectral features: mafic (pyroxene, olivine…) as well as hydrated and altered minerals that are key phases for the solar system bodies' exploration.

1. Introduction

Coupling imaging to spectroscopy has proven to play a major role in the compositional characterization of solar system bodies. The hyperspectral imagers provide numerous insights on the surface mineralogy and atmosphere of planetary bodies, as for instance, the OMEGA (Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité) and CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) instruments orbiting Mars ((Bibring et al., 2004) (Murchie et al., 2007),), VIRTIS (Visible Infrared Thermal Imaging Spectrometer) around Venus (Drossart et al., 2007) and comet 67P/Churyumov-Gerasimenko (Coradini et al., 2011), and VIMS (Visible and Infrared Mapping Spectrometer) in the saturnian system (Brown et al., 2006). All these imaging spectrometers operate in the visible and infrared wavelength range to provide global and regional coverage of the studied bodies with 10-m to less than km spatial resolution. In order to perform similar measurements dedicated to exploring the surface of any planetary body but at microscopic scale from in-situ platform, a new type of instrument has been developed at Institut d'Astrophysique Spatiale (IAS) named MicrOmega (Leroi et al. (2009), Pilorget and Bibring (2013)). This is an infrared hyperspectral imaging microscope with the first model in operation currently on board the Hayabusa-2 mission (Tsuda et al. (2013)). A new model is currently under development for the ExoMars2020 rover. Because observations at microscopic scale resolve grains, they may permit the detection of minor phases not detectable from orbit, the characterization of samples at their grain scale and coordinated analyses with orbital macroscopic data.

The MicrOmega instrument is a part of the payload of MASCOT (Mobile Asteroid Surface sCOuT) a 10 kg lander developed by Deutsches Zentrum für Luft (DLR) and Centre National d'Etudes Spatiales (CNES) carried by the Japan Aerospace Exploration Agency (JAXA) Hayabusa-2 spacecraft. The spacecraft was successfully launched in December 2014 to characterize and ultimately to bring back samples from a C-type asteroid (1999 JU3 RYUGU). The study of this C-type asteroid will provide new insights into the origin and evolution of asteroids and better constrain the story of water and organic matter in the solar system. The MASCOT lander will perform measurements during 10–15 h after landing on the asteroid, the lifetime being limited by battery capacity. Depending on where it will land, the environmental temperature expected on the asteroid varies between∼−100 °C and ∼+100 °C. The highly limited duration of operation for the measurements once on the asteroid will prevent ground in the loop interaction with the lander or the

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https://doi.org/10.1016/j.pss.2018.01.009
Received 28 June 2017; Received in revised form 14 December 2017; Accepted 16 January 2018
Available online 31 January 2018

testing of parameters before acquiring the first dataset. For instance, the integration time will have to be fixed before data acquisition. It is thus important to evaluate beforehand how the observational conditions (primarily the thermal contribution) affect background levels, in order to estimate the operational parameters to prevent saturation while maximizing the signal to noise ratio (SNR).

The complexity of the data type (hyperspectral images) also requires an in-depth on-ground calibration to enable the scientific interpretations of the data and to optimize data reduction and analyses. The on-ground calibration consists of characterizing the instrument response as a function of all instrumental parameters and modes. It includes the evaluation of the overall instrument performances and characteristics in terms of radiometric and spectral responses according to the environmental and operational parameters.

First, in section 2 we present a brief description of the instrument design and operation to explain the calibration objectives. The calibration setup and interfaces are described in section 3, followed by the measurement protocols. The calibration process is presented in three sections to account for the different aspects of the calibration: thermal contribution and Signal to Noise Ratio (SNR) evaluation in section 4, and radiometric (section 5) and spectral calibrations (section 6). Finally, in section 7 the calibration results will be discussed in terms of performance. Reflectance spectra of minerals will be shown and compared with laboratory spectra. In this paper, we focus on MicrOmega' short wavelength range channel (wavelengths from 0.99 to 2.5 μm). A further paper will deal with the long wavelength range (2.5–3.55 μm).

2. The MicrOmega experiment

2.1. Instrument presentation

The near-infrared hyperspectral microscope MicrOmega will perform non-destructive in-situ measurements of scenes of $3.2 \times 3.2\ \mathrm{mm}^2$ with a spatial sampling of 25 μm (128×128 pixels^2). It operates between 0.99 μm and 3.55 μm with a spectral sampling of typically $20\ \mathrm{cm}^{-1}$ which corresponds to 2–25 nm at 1 μm–3.55 μm respectively. Additionally, a calibration target made of de-polished sapphire with a chromium coating is placed on the window, masking a small fraction of the field of view. This calibration target will be used once in operation to monitor potential variations in the instrumental response (Bibring et al., 2017).

MicrOmega is divided into two main parts: the MicrOmega Electronic Unit (MEU) accommodated inside the MASCOT common Electronic box (Ebox) and the MicrOmega Sensor Unit (MSU); the summed mass is about 2 kg. The MSU (Fig. 1) is composed of several subsystems including: the RF synthesizer, the illumination and imaging optics, the AOTF (Acousto-Optic Tunable Filter), the detector and cryocooler. The window from which the samples are imaged is implemented outside of the main structure, to get in contact with the samples, thus imaged at a known distance without requiring any mechanism.

The dispersive system is based on an acousto-optic tunable filter (AOTF) with a spectral response having a full width at half maximum (FWHM) of $20\ \mathrm{cm}^{-1}$. A radio frequency (RF) signal is sent into a TeO_2 crystal through a piezo transducer, in which it creates an ultrasonic acoustic wave propagating throughout the crystal. This electronically produced acoustic wave induces a periodic variation of the refractive index of the crystal that interacts with the incident polychromatic light beam (produced by a tungsten lamp with a color temperature of 2200 K). The interaction between the incident illuminating light beam and the acoustic wave produces a beam of specific wavenumber (or wavelength) in a fixed direction at the crystal output which permits the monochromatic illumination of the sample. This wavelength is imposed by that of the acoustic wave. The wavelength range (3.55–0.99 μm) corresponds to piezo transducer frequencies from $2.65.10^7$ Hz to $9.90.10^7$ Hz: the sequential spectral selection of the illuminating beam is performed by scanning the frequency of the acoustic wave. The tuning relation to convert the RF signal frequency into illuminating light wavelength units

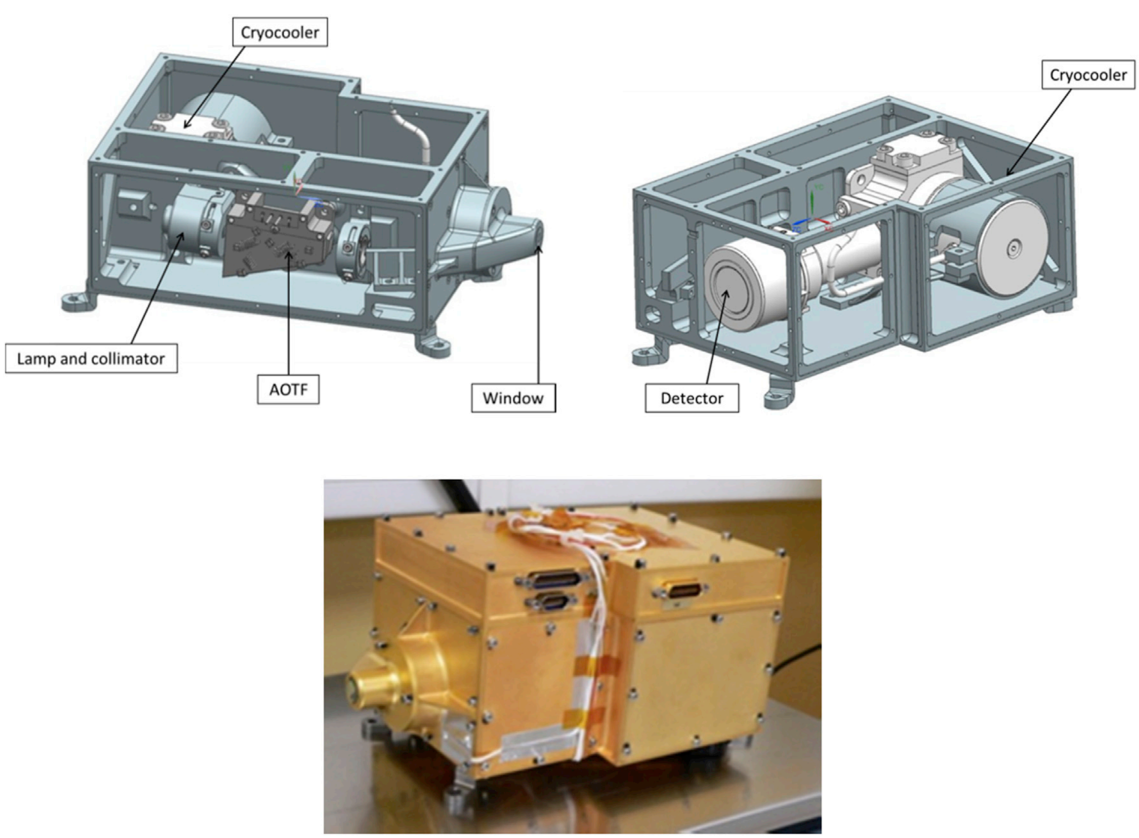

Fig. 1. Flight model of MicrOmega/Hy2 (MSU).