The measurement of the noise-equivalent spectral radiance of SIMBIO-SYS/VIHI spectrometer

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***Abstract*—We report about the measurement of the Noise-Equivalent Spectral Radiance (NESR) of the VIHI imaging spectromter aboard ESA's Bepi Colombo mission to Mercury. The knowledge of the NESR allows to determine the capability of an optical detector to measure faint signals. A description of the setup used to determine the NESR during the prelaunch calibration campaign is given. The processing of the data collected at various operative temperatures and integration times is described. The sensitivity study of the NESR has been performed at the expected detector's temperatures and integration times with the goal to determine the minimum spectral radiance at which VIHI is sensitive during the different observation phases of the mission.**

***Index Terms*—NESR, spectrometer, VIS-NIR radiance**

I. INTRODUCTION

The Visible and Infrared Hyperspectral Imager [1] is the spectral channel of the SIMBIO-SYS optical payload [2] aboard ESA's mission Bepi Colombo to Mercury. The integrated remote sensing suite of cameras and spectrometer SIMBIO-SYS (Spectrometer and Imagers for MPO BepiColombo-Integrated Observatory SYStem) has been realized with the aim to realize an high spatial resolution global mapping of Mercury surface at visible and near infrared wavelengths. The payload includes 3 optical channels: 1) a High Resolution Imaging Channel (HRIC); 2) a Stereo Colour camera (STC) and 3) a Visible and near Infrared Hyperspectral Imager (VIHI). In this work we report about the measurement of the VIHI NESR performed during the prelaunch calibration campaign executed at Leonardo Company in Campi Bisenzio (Florence, Italy) premises, price industrial contractor of the SIMBIO-SYS payload. VIHI instrument operates within the 0.4-2.0 μm spectral range in 256 spectral bands with a spectral sampling of 6.25 nm/band. The instrumental FOV is 64 mrad wide and is imaged by means of 256 spatial pixels, each with a 250 μrad Instantaneous Field Of View (IFOV). The spectrometer is designed to operate from the 400 km altitude polar orbit of the BepiColombo spacecraft in pushbroom mode to cover a 25.6 km-wide swath on ground with 100 m/pixel resolution.

II. Measurement of the NESR

In order to determine the effective radiometric performances of the instrument we have used a dedicated radiometric calibration setup [3] with the aim to measure the NESR. The instrumental spectral response is detailed in [4]. The NESR indicates the minimum spectral radiance in W/(m^2 μm sr) at which VIHI is sensitive, e.g. the spectral radiance corresponding to a signal of 1 DN. This is the minimum signal which can be measured by the detector. The NESR is defined as the ratio of the standard deviation of the sum of the dark current and external background with the responsivity:

$$NESR = \frac{STDEV[D(\lambda) + B(\lambda)]}{R(\lambda)} \quad (1)$$

where $D(\lambda)$ is the dark current, $B(\lambda)$ is the background, equivalent to the sky, and $R(\lambda)$ is the instrument's responsivity at wavelength λ. The VIHI's responsivity has been determined by means of the radiometric calibration measurements [3] by using the reference flux given by an integrating sphere [5]. The $D(\lambda) + B(\lambda)$ signal is measured by acquiring a black screen placed at the entrance window of the thermo-vacuum chamber in which the VIHI OH is housed during the measurements. In order to explore the instrumental performances at different operative cases, many dark current and background frames are measured at the three operative temperatures of the detector: 1) nominal temperature T_n=220 K; 2) low temperature T_l=210 K; high temperature T_h=225 K. While the detector's temperature is expected to vary with the different orbital phases of the mission and is stabilized by means of an active thermoelectrical control (TEC), the spectrometer's optical bench is controlled by thermal conductance through the spacecraft interface and is maintained at nominal temperature of T=278 K. A series of integration times ranging from readout to 10, 20, 30 up to 500 msec were acquired for T_l case. With the increase of the detector's temperature, the maximum integration time is reduced to 250 msec for T_n and 200 msec for T_h. This is consequence of the increase of the dark current and occurrence of saturation conditions. A total of 100 acquisitions are collected for each integration time at T_n case while 50 are taken for both T_l and T_h cases. These multiple acquisitions are necessary to derive the standard deviation used in Eq. 1. In figures 1, 2, 3 are shown the resulting NESR profiles (averages above the 256 spatial samples) for the series of integration times acquired for detector's temperatures T_n, T_l and T_h, respectively. Spikes visible on the plots are due to the occurrence of unfiltered hot pixels on the detector [3].

As a consequence of the strong dependence of the dark current rate with the detector's temperature which increases from 12.29 to 40.29 up to 72.55 DN/msec at T_l, T_n, T_h respectively [3], the NESR deteriorates at longer integration times and higher temperatures because it depends from fluctuations of the dark current. In these conditions VIHI shows a worse sensitivity to lower radiances. For a typical 50 msec integration time at λ=1.3 μm, where the instrument's response is maximum, the resulting NESR is equal to: $6 \cdot 10^{-3}$ W/(m^2 μm sr) at T_l=210 K (Fig. 1); $1.5 \cdot 10^{-2}$ W/(m^2 μm sr) at T_n=220 K (Fig. 2); $2.5 \cdot 10^{-2}$ W/(m^2 μm sr) at T_h=225 K (Fig. 3). In all three cases the allowable NESR upper values are limited by the detector's full-well capacity (2 Me$^-$ per pixel) corresponding to a saturation level of about 13.200 DN after digitalization of the signal.

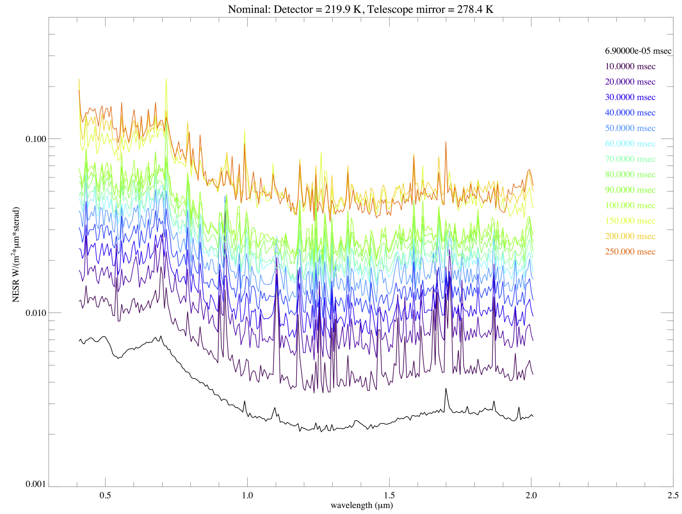

Fig. 1. VIHI NESR profiles for integration time between readout and 250 msec at detector's nominal temperature T_n=220 K.

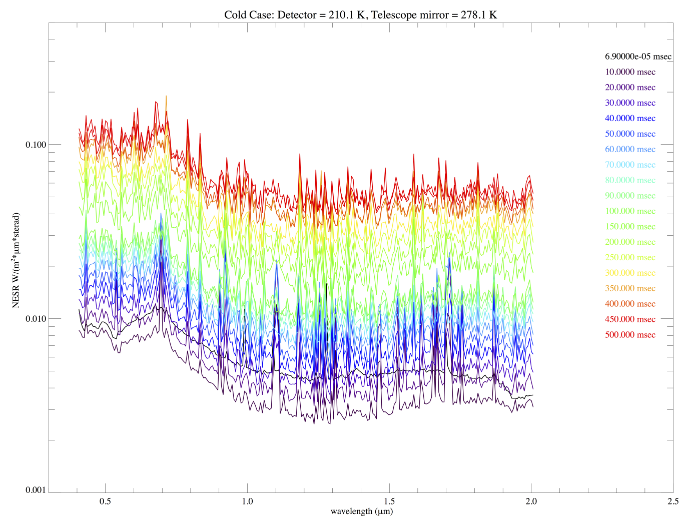

Fig. 2. VIHI NESR profiles for integration time between readout and 500 msec at detector's low temperature T_l=210 K.

III. Conclusions

The VIHI spectrometer has been completely characterized during the prelaunch calibration campaign. By adopting specific measurement setups, VIHI's linearity, radiometry, geometry and spectral responses were determined [3], [4]. This work about the measurement of the instrumental NESR has to be considered as an addendum to these previous works, allowing to quantify the limits of the instrumental radiometric response and to derive the expected signal to noise ratio for different observation scenarios. A similar knowledge will permit to the

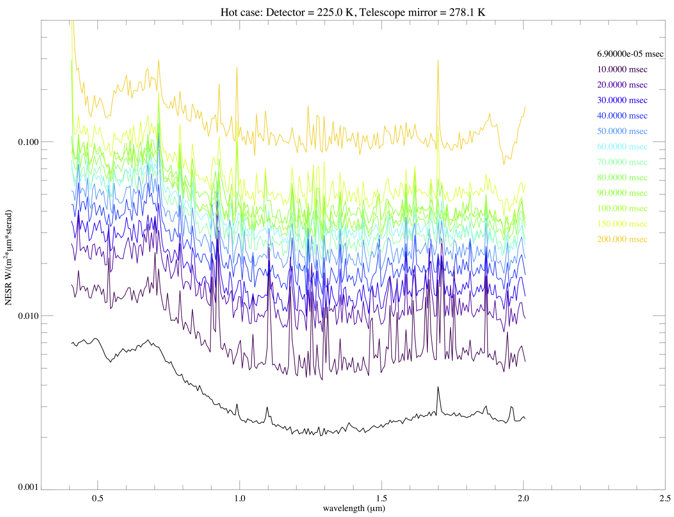

Fig. 3. VIHI NESR profiles for integration time between readout and 200 msec at detector's high temperature T_h=225 K.

science team to implement the optimal observation strategy at Mercury.

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