Mem. S.A.It. Suppl. Vol. 12, 72
© SAIt 2008

Memorie della
Supplementi

Radiometric Model and Operation-Define-Tool for HRIC SIMBIO-SYS on the BepiColombo mission to Mercury

M. Zusi[1,2], L. Colangeli[2], P. Palumbo[3], E. Mazzotta Epifani[2], G. Marra[2], E. Flamini[4], and the SIMBIO-SYS International Team

[1] Aerospatial Engineering Department, University of Naples "Federico II", Piazzale Tecchio 80, 80125 Naples, Italy
[2] National Institute of AstroPhisics - Astronomical Observatory of Capodimonte, Salita Moiariello 16, 80131 Naples, Italy
[3] Applied Science Departement, University of Naples "Parthenope", Centro Direzionale - Isola C4, 80143 Naples, Italy
[4] ASI, Italian Space Agency, Viale Liegi, 26, 00198 Roma, Italy

Abstract. BepiColombo is an Interdisciplinary Cornerstone ESA Mission aimed at understanding the formation and the evolution of Mercury, the innermost planet of the Solar System. The High Resolution Imaging Channel (HRIC) on the SIMBIO-SYS experiment is one of the BepiColombo payload components, which will analyse surface morphology due to endogenic/exogenic processes and will support libration experiments with high precision measurements. In order to study and improve the performances of the HRIC, a Radiometric Model (RM) has been developed to determine the image quality of planet observations under different operative conditions. An Operation-Define-Tool (ODT) software combines the RM with the orbital parameters derived from the ESA's official long-term planning operation software (MAPPS) for Mercury. The ODT is a target-oriented program, useful to evaluate the coverage and the geometric conditions in which a specific target will be imaged.

Key words. Planets: Mercury – Space missions: BepiColombo – Instruments: SIMBIO-SYS, High Resolution Imaging Channel

1. Introduction

BepiColombo is an Interdisciplinary Cornerstone ESA-JAXA Mission with the aim of understanding the formation and the evolution of Mercury, the innermost planet of the Solar System. The main objectives of the mission can be grouped as it follows:

1. Analysis of the structure and dynamics of Mercury Magnetosphere;
2. Estimation of the internal structure and composition;
3. Characterisation of the surface composition and morphology, as consequence of endogenic and exogenic processes (Vilas et al. 1988);

4. Determination of Exosphere composition and dynamics.

The mission consists of two orbiters (Mercury Planetary Orbiter - MPO from ESA and Mercury Magnetometric Orbiter - MMO from JAXA), which will be launched in the second half of 2013 from Kourou. After an interplanetary journey of about 6 years they will enter in the orbit of Mercury.

The Spectrometer and Imager for MPO Bepicolombo Integrated Observatory - SYStem (SIMBIO-SYS) is the MPO suite which has the objective to characterise the morphology and chemical/mineral composition of the planet surface with very high performance (Anselmi & Scoon 2001). It consists of three optical heads: the High Resolution Image Channel (HRIC), the STereo Channel (STC) and the Visible and near-Infrared Hyperspectral Imaging channel (VIHI).

The High Resolution Imaging Channel (HRIC) of SIMBIO-SYS, designed and developed under the lead of INAF - Astronomical Observatory of Capodimonte in Naples (Colangeli et al. 2006), has the main objective of characterising the morphology of planet surface, due to both endogenic and exogenic processes, with high spatial resolution (5 m/pix scale at 400 Km of altitude). Its planned observational activities foresee:

– Surface coverage of about 20% of the planet surface at high spatial resolution;
– Observation of interesting surface target (about 5% of the total amount of observations) at maximum spatial resolution;
– Localisation of key superficial features, like scarps, lava flows, plains and craters for planet age estimation (Neukum et al. 2001; Watters et al. 2001).

Thanks to its high spatial resolution, HRIC will also support the libration experiments in determining the anomalies in its rotational motion and the measurement of the Mercury orbital axe obliquity.

The present configuration of HRIC can be subdivided in two main parts:

– Optical Elements: The optical configuration is catadioptric and it is diffraction limited at 400 nm (Marra et al. 2006). It optimises radiometric flux and overall mechanical dimensions, guarantying a good balance of achieved optical performances and optimisation of resources (mainly, instrument volume and mass);
– Detector Components: The corrected field of view (1.47°) will be covered by an innovative CMOS hybrid sensor of 2k x 2k pixels, with pixel size of 10 μm. Four filters will be placed in front of the SiPIN sensor: a panchromatic (centred at 650 nm with 500 nm of bandwidth) and three broadband (all with 40 nm of bandwidth and centred at 550 nm, 700 nm and 880 nm).

Operations have to be carefully planned to properly combine MPO orbital characteristics with HRIC configuration in order to achieve the main goals of the missions. For this purpose, a Radiometric Model and an instrument simulation tool (Operation Define Tool - ODT) have been developed with the aim to reproduce the expected camera performances as a function of operative conditions.

2. Radiometric Model and Operation Define Tool

In order to characterise and improve the behaviour of the HRIC camera, a Radiometric Model (RM) has been developed; it analytically describes how the camera converts the impinging radiant flux into an image at every operative conditions. A software tool (Operation-Define-Tool) combines the RM with the orbital parameters coming from ESA's Mercury official long-term planning operation software (Mapping And Planning Payload Science - MAPPS) in order to estimate the entity end quality of planet observations.

The Radiometric Model is a mathematical description of the instrument behaviour with respect to the following input parameters:

– Input radiant flux coming from the planet;
– Optical and sensor properties;
– Input or built-in noise sources that may degrade the quality of the produced image.

One of the most important RM output is the Signal-to-Noise-Ratio (Epifani et al. 2006) which describes the overall instrument performance over a scene with respect to:

- Acquisition geometry (perihelion angle, phase angle, Sun elevation, Spacecraft latitude and longitude, etc.);
- Observational Parameters (Albedo coefficient, used filter, exposure time and all the optics and sensor description parameters).

The analytical expression of the SNR referred to each sensor pixel (SNR_{pixel}) is:

$$SNR = \frac{s(e^-)}{n(e^-)}$$

where:

$$s(e^-) = P \cdot t_{int} \cdot E_{opt} \cdot \frac{1}{N_{pix}} \cdot E_{filt} \cdot E_{supp} \cdot F_E$$

$$P = \frac{4}{\pi} \cdot Sun_{flux} \cdot \cos(lat) \cdot EP \cdot A_{vis} \cdot \tan^2(\frac{FOV}{2})$$

$$F_E = \frac{\int_{\Delta\lambda} \frac{\lambda}{h \cdot c} \cdot B(\lambda) \cdot E_{hrf}(\lambda) \cdot QE(\lambda) \cdot A_n(\lambda) d\lambda}{\frac{\sigma \cdot T^4}{\pi}}$$

$$n(e^-) = \sqrt{\sigma_S^2 + (DC \cdot t_{int}) + \sigma_{ele}^2 + \sigma_{ro}^2 + \sigma_{ADC}^2}$$

and:

- "P" is the input power coming from the planet surface under a specific observation geometry (perihelion angle, latitude etc.);
- "F_E" is the conversion factor (number of electrons over energy) to transform the input power "P" in number of electrons;
- "n(e^-)" is the noise term that affects the acquired signal of each sensor pixel.

The main objective of a RM is to identify and correctly model all the noise sources that may reduce the quality of the acquired image. The following contributions have been identified:

1. Photon Noise (σ_S^2): it represents the standard deviation (equal to the RMS of photons arrival) of the Poisson (or Gaussian) distribution that describes the non homogeneous photons arrivals over sensor cells;
2. Dark Current (DC): it represents the contribution of the Thermal Noise. This process determines in a silicate composite cell (like the ones of a CMOS sensor) a spontaneous production of free charges that are collected by the following electrical circuits producing a weak useful signal;
3. Electron Noise (σ_{ele}^2): it is a noise contribute given by the circuital components that amplifies and transmits the collected signal (generally specified by the producer);
4. Readout Noise (σ_{ro}^2): it consists of a spurious charge contribution given by the non ideal behaviour of the sensor reader (generally specified by the producer);
5. Quantization Noise (σ_{ADC}^2): it is the noise contribution given by the approximation operation necessary to convert the continuous dynamics of the analogue input into a discrete signal whose amplitude values are defined by the ADC bit numbers.

The developed RM foresees also another formulation of the SNR expression that takes care of other noise contributions, affecting the image quality over the entire frame (SNR_{frame}). These additional terms derive from the different behaviour of the sensor pixels and their readout integrated circuits and are:

- Photo Response Non Uniformity contribution: this term derives from the different responsivity function that characterises each pixel;
- Dark Current Non Uniformity contribution: even if all the pixels operate at the same temperature they may be characterised by a different rate of spontaneous charge production (DC);
- Fixed Pattern Noise contribution: in sensor read operation, the reset procedure may leave some residual non homogeneous distributed charge over the entire frame.

These noise terms determine a global effect of a non homogeneous illumination offset over the produced image that can be reduced/eliminated applying Flat-Field (sensor exposure to a homogeneous illumination), Dark Frame (sensor exposure with no illumination - shutter closed) and BIAS (instantaneous sensor exposure) subtraction.

An example of Signal to Noise Ratio curves over a frame is shown in Figure 1.

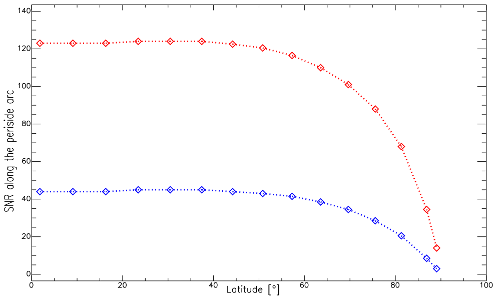

Fig. 1. Signal to Noise Ratio curves. SNR on images acquired along the periside orbital arc and considering Bright (red line - Albedo = 0.3) and Dark Regions (blue line - Albedo = 0.06).

The other instrument involved in the development of the Operation Define Tool (ODT) is MAPPS, the ESA's official tool for long-term operations planning. Through its features it is possible to project over a Mercury map the observations of all the Mercury Planetary Orbiter instruments in order to estimate the entity of the surface coverage. This graphic output can be used to evaluate observation opportunities in real geometric conditions all over the mission lifetime.

A particular and interesting feature of MAPPS is the possibility to retrieve observational geometric information, such as Spacecraft latitude and longitude, Sun elevation, time from pericenter etc. at every acquisition instant. Starting from these very precise observational geometric information, relative to a particular superficial target, and applying the Mercury RM it can be possible to build an observational grid to project over a Mercury map in which:

- Grid cell overlapping shows the coverage degree;
- Colour shade reflects the quality (SNRframe) of each observation.

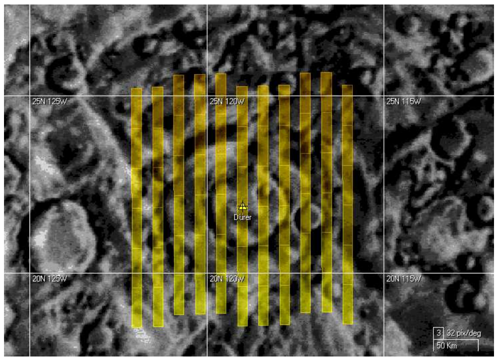

Fig. 2. ODT output 1. Coverage degree and observation quality at periside arc.

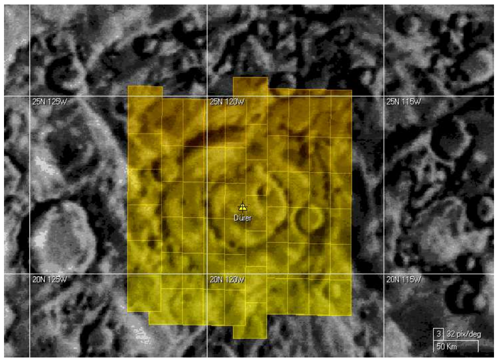

Fig. 3. ODT output 2. Coverage degree and observation quality at aposide arc.

Figure 2 and Figure 3 report two examples of the ODT output: the first refers to the HRIC observation along the periside arc (the Spacecraft is between about 400 and 900 Km from planet surface) in subsequent orbits; the second refers to the aposide arc (the Spacecraft is between about 900 and 1500 Km from planet surface).

The output of ODT can be very useful to plan HRIC operations in order to maximise the scientific output of the observations. As an example, the analysis of the degree and quality of coverage can be used to establish the importance or the scientific priority of an observation with respect to the HRIC allocated resources (especially data volume and data rate budget).

3. Conclusions and future developments

In this paper we have presented the ongoing activity in support to HRIC development for the preparation of a tool (Operation Define Tool) that combines the Mercury Radiometric Model and observational geometric information (from ESA MAPPS tool) in order to project over a Mercury map a grid that represents the coverage capabilities of HRIC in terms of percentage and image quality. In this manner it shall be possible to plan the camera observations in order to maximise the scientific return efficiently using Spacecraft resources.

Acknowledgements. We gratefully acknowledge funding from the Italian Space Agency (ASI) under contract I/090/06/0. SIMBIO-SYS is an international project led by Italy, with major contributions from France and Switzerland.

References

Vilas F., et al. Eds. 1988, Mercury, University of Arizona Press, Tucson

Anselmi A., & Scoon G.E.N. 2001, Planetary Space Science, 49, 1409

Colangeli L., et al. Eds. 2006, Memorie della Societa Astronomica Italiana Supplement, v.9, p.170

Neukum G., et al. 2001, Planetary Space Science, 49, 1445

Watters T.R., et al. 2001, Planetary Space Science, 49, 1523

Marra G., et al. 2006, Optomechanical Technologies for Astronomy, SPIE, ApJ, 6273, 627328

Epifani M.E., et al. 2006, European Planetary Science Congress 2006, Berlin, Germany, p.67