BC-SIM-TN-SOIM MANUAL

(Simulator for Operation of Imaging Missions)

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# Index

[1. Index 2](#_Toc119401508)

[2. Introduction 4](#_Toc119401509)

[2.1. Scope 4](#_Toc119401510)

[2.2. Reference Document 4](#_Toc119401511)

[2.3. Acronyms 5](#_Toc119401512)

[2.4. Document Format and Repository 5](#_Toc119401513)

[2.5. Software Version 5](#_Toc119401514)

[2.6. Document organization 6](#_Toc119401515)

[3. Software Description 7](#_Toc119401516)

[3.1. Objective and structure 7](#_Toc119401517)

[4. Input 10](#_Toc119401518)

[4.1. Textual 10](#_Toc119401519)

[4.2. SK Inputs 10](#_Toc119401520)

[4.3. Input timeline file 11](#_Toc119401521)

[4.4. Internal option 11](#_Toc119401522)

[5. Output 13](#_Toc119401523)

[6. Future improvements 16](#_Toc119401524)

[7. Competition and criticism 17](#_Toc119401525)

**Approvation**

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**Document Change Record**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Issue | Revision | Date | Affected Pages | Change description |
|  |  |  |  |  |
|  |  |  |  |  |
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# Introduction

## Scope

In this document, we will describe the Simulator for Operation of Imaging Missions (SOIM) software used for the simulations of the the Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem (SIMBIOSYS).

The document will provide documentation and the description of the input and output file.

## Reference Document

1. BC-SIM-TN-003 – Reports and Notes Layout and Flow – Version 2

[10.20371/INAF/TechRep/179](https://doi.org/10.20371/INAF/TechRep/179)

1. BC-SIM-TN-002\_-\_STC\_Strategy\_Observation

[10.20371/INAF/TechRep/35](http://dx.doi.org/10.20371/INAF/TechRep/35)

1. BC-SIM-TN-009\_-\_STC\_GM\_Observation\_Strategy\_Optimization\_20220706

[10.20371/INAF/TechRep/173](https://doi.org/10.20371/INAF/TechRep/173)

1. BepiColombo MCAM Channels Spice Kernels Optimization

[10.20371/INAF/TechRep/125](https://doi.org/10.20371/INAF/TechRep/125).

## Acronyms

**CSV** Comma Separated Values

**FPA** Focal Plane Assembly

**HRIC** High spatial Resolution Imaging Channel

**MCAM** Monitoring CAMeras

**ME** Main Electronics

**PNG** Portable Network Graphics

**SIMBIO-SYS** Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem

**SK** Spice Kernels

**SOIM** Simulator for Operation of Imaging Missions

**STC** STereo imaging Channel

**TC** Telecommand

**VIHI** VIsible and Hyper-spectral Imaging channel

**XML** eXtensible Markup Language

## Document Format and Repository

This document is compliant with the SIMBIO-SYS Report and Note Layout and Flow [RD.1] and will be archived both on the INAF Open Access repository and the SIMBIO-SYS team Archive.

## Software Version

Version 6.0

## Document organization

Section 3 will describe the software, its objectives and its structure

Section 4 will describe all the input required and the format needed to import the input.

Section 5 will describe all the parameters evaluated and reported in the output.

Section 6 and 7 will report the current proposal for future implementations and a short paragraph of conclusion to underling the criticisms undelighted during the development of this pipeline.

# Software Description

The experience accumulated by INAF in International Space Missions has demonstrated the impact and the scientific return of Imaging tools. These instruments have required, in all mission phases, the development of tools to simulate acquisitions, to verify and optimize the observation strategy, and to define the essential parameters for Operations. The Simulator for Operation of Imaging Missions (SOIM) will be a generic software tool for the simulation of such payloads. It was developed thanks to the contribution of INAF-OAPD; INAF-IAPS; CNR-IFN and will represent a transversal activity to different research lines favoring the optimization of performances and, with the collaboration of the scientific group, the validation of scientific requirements.

## [Objective](https://schede.inaf.it/consulta/mostra?selezione=62270e3a147463c860ebb1fa&modalita=LONG) and structure

Almost all of the imaging tools in the planetological field can be modeled as pin-hole tools (definable by a pinhole model similar to the classic operation of a dark room). These tools represent the key to planetological exploration by providing images that allow both morphological and radiometric analysis of the bodies of the solar system. The experience of our group, in the context of planetary exploration missions, has highlighted the lack, within INAF, of a tool for the simulation of these instruments linked to the Operational side, which is essential, from the earliest stages of design, to verify and simulate the acquisition capabilities of the same with an impact, on risk factors, time and accuracy, of the development of the payload.

For this reason, the development of the SOIM software has begun, currently in use for the SIMBIO-SYS tool (BepiColombo).

In terms of Operation of a planetary mission, many of the necessary parameters are defined starting from the following inputs:

1) The ephemeris that imply the lighting conditions of the observation scenario

2) the instrument model

3) the model of the target

For missions already in progress, the first are provided directly by the reference agencies as in the standard Spice Kernel (SK) format. In the case of future missions, the development of the SK can be integrated with the definition of possible new scenarios.

Diagram

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*Figure 1 Block diagram for the generation, on the basis of the requested timeline, of the simulation outputs (in green) based on the ephemeris and of the models (in blue). The dashed flows represent the information that can be integrated into the SKs (if absent)*

Once the orbit has been defined and a 3D model (even approximate) of the body integrated, it is possible to obtain the lighting angles of each region of the instrument's field of view and consequently the input flux to the instrument, allowing to validate an operational timeline.

The instrument model is formalized through two sub-models: the geometric one and the opto-electric one. The first defines the projective system of the chamber. The opto-electric model defines the response of the sensor to the input flow in terms of gain (linked to the filters and the pupil) and in terms of dark (or an approximation of it verifiable during the calibration phase). If the geometric model is defined during the calibration phase, the opto-electrical model, which can be approximated by a few parameters, can be deduced from the earliest stages of optical and sensor design.

The target model is nothing more than the radiometric model of the observed body. This can be defined generically, for lesser known bodies, or specifically if it is known from other missions. This is the case of the BepiColombo mission which will exploit, as a first estimate of the radiometric models, the knowledge of Mercury provided by previous missions.

The software's first-level outputs will be linked to image quality and target visibility.

As for image quality, the system allows you to define integration times in order to avoid saturation or smearing. As regards the visibility of the target, in addition to verifying it, it allows to estimate the repetition time to be used to guarantee a defined overlap of the images (see Figure 2) and to provide the mapping of the planet's acquisitions as well as a synthetic simulation of what expected. Products connected to this task are the shapefiles of each acquisition provided for all the three channel of SIMBIO-SYS and used for the study and optimization of the Observation Strategi of VIHI and STC (see [RD.2] and [RD.3]).

Chart

Description automatically generated

Figure Example of simulator product in the case of polar acquisitions by STC. The two channels (respectively in blue and in red) of the instrument are oriented in a non-nadiral way. The SOIM allows to evaluate on the one hand the repetition time to ensure overlapping between acquisitions; on the other hand, it also provides shapefiles for verifying the target regions actually framed.

With the current version of the simulator, it was possible, for example, to simulate the closest approach images of the first Mercury flybys by the navigation cameras (MCAMs) of BepiColombo as shown in the example in Figure 3.

This allowed to outline the timelines for the acquisitions and to validate the geological features taken during these phases.

The same process was also used for the optimization of the models of the cameras themselves by correcting the aiming of these cameras provided by the SKs as reported in ([RD.2]).

Background pattern

Description automatically generated with medium confidence

Figure Example of simulator products. In (a) the rendering of the 3 cameras at 5-minute intervals in a neighborhood of the C.A; in (b) a subsection of these images which highlights on the one hand the region concerned and on the other the position of the terminator. In (c) summary of one of these simulations which shows the synthetic image on the left, on the right the equirectangular map of mercury with the region acquired from the image highlighted and the maps of the phase and incidence angles within the FoV.

# Input

Once runned the simulator. It ask the main important parameters of the simulation which can be inserted manually in the Define Simulation Window shown in Figure 2.

Graphical user interface, text, application

Description automatically generated

Figure define Simulation window showing the main input which can be define.

## Textual

This inputs includes:

* Local Path of the Mice folder in the PC used
* Local Path of the spice kernels to be considered (the folder must contain a “mk” subfolder with a list of plan file with extension TM. The simulation will consider the most recent)
* Target of the simulation
* Reference frame to be considered
* S/C Observer name

## SK Inputs

Also Spice kernel IDs can be selected by the Define Simulation Window. The NAIF IDs currently included in SOIM are reported in Table 1 but additive on can be added extending variable instruments\_id in “Read\_DEFAULT\_definitions.m”.

**NAIF ID refers to the frame kernel to be considered for the interested push broom or push frame camera.**

Table NAIF ID of the Frame Kernels currently defined in the SOIM

|  |  |
| --- | --- |
| NAME | NAIFID |
| MPO\_SIMBIO-SYS\_HRIC\_F550 | -121611 |
| MPO\_SIMBIO-SYS\_HRIC\_FPAN | -121612 |
| MPO\_SIMBIO-SYS\_HRIC\_F750 | -121613 |
| MPO\_SIMBIO-SYS\_HRIC\_F880 | -121614 |
| MPO\_SIMBIO-SYS\_STC-L\_F920 | -121623 |
| MPO\_SIMBIO-SYS\_STC-L\_F550 | -121624 |
| MPO\_SIMBIO-SYS\_STC-L\_P700 | -121625 |
| MPO\_SIMBIO-SYS\_STC-H\_P700 | -121626 |
| MPO\_SIMBIO-SYS\_STC-H\_F420 | -121627 |
| MPO\_SIMBIO-SYS\_STC-H\_F750 | -121628 |
| MPO\_SIMBIO-SYS\_VIHI\_FPA | -121630 |
| MTM\_MCAM1 | -652950 |
| MTM\_MCAM2 | -652960 |
| MTM\_MCAM3 | -652970 |

One selected the Apply button a window for the selection of the time information file will be opened.

## Input timeline file

Input file is a text file providing the timing information for the simulation.

As reported in following example (see Table 2) the txt file reports in three line the UTC beginning of the simulation, the end of the simulation, both in the format “*DD-MMM-YYYY hh:mm*” and the sampling of the simulation in seconds.

Table Example of the txt file used to define the timeline

|  |
| --- |
| 14-Mar-2026 00:00 # start time  20-Apr-2026 23:59 # stop time  1 # sampling [sec] |
|  |
|  |

## Internal option

param\_method.abcorr='LT+S';

param\_method.method='Ellipsoid';

# Output

Output file can be an XLS,XLSX,CSV file containing all the simulated acquisition required in the timeline. Each line correspond to an acquisition, evaluated parameters are described in Table 3.

Table Results of the simulation described as output of the XLSX file. For each output parameter is reported a brief description and an example extracted by the simulation of the Aphelion 1 for the HRIC instrument in case of a 30 km orbit.

|  |  |  |  |
| --- | --- | --- | --- |
| **Reference Field** | Name | Colum | Definition |
| **Time** | UTC | A | Time of the acquisition in UTC in ISO Calendar format.  It is the result of the Naif conversion script:   |  | | --- | | cspice\_getfov( instr\_id, 4) |   i.e.  2026-05-11T00:00:00.00 |
| Epoch [s] | B | Ephemeris time[s] expressed as ephemeris seconds past J2000.  i.e.  831729669.185337 |
| Epoch Relative [h] | C | Ephemeris time(h) expressed as ephemeris seconds past J2000 relative to the beginning of the simulation.  i.e.  0 |
| **Distances** | SurfDist [km] | D | Surface distance in Km respect the observer. Surface is considered as defined in Section 2.1.  i.e.  615.575775884503 |
| Subnad   Dist  [km] | Y | Distance in Km of the subnadiral point respect the observer.  Note that the emission angle has a strong impact on this distance.  i.e.  615.575775884503 |
| Terget  2Sun  [km] | Z | Distance in km between the observer and the Sun  i.e.  48465621.1868789 |
| **Boresight** | Lat,Long Bor  [°] | E-F | Latitude and longitude [°] in the point defined by the intercept between the instrument boresight and the surface considered (see Section 2.1)  i.e.  67.92225657 45.96994191 |
| Radius     Bor  [km] | G | Ray of the planet in the point in the point defined by the intercept between the instrument boresight and the surface considered (see Section 2.1)  i.e.  2439.7 |
| Phase,Solar,Emiss  Bor  [°] | H-I-J | the illumination angles in the point defined by the intercept between the instrument boresight and the surface. Bot the surface and the aberration corrections considered are defined in Section 2.1:   * phase angle is the angle between the ‘boresight intercept’-'observer' vector and the ' boresight intercept '-sun vector. Units are in degree. The range of 'phase' is [0, 180]. * Solar angle (called incidence ) is the angle between the surface normal at ‘boresight intercept’ and the ' boresight intercept '-sun vector. Units are in degree. The range of 'solar' is [0, 180]. * Emission angle (called incidence ) is the angle between the surface normal at ‘boresight intercept’ and the ' boresight intercept '-observer vector. Units are in degree. The range of 'solar' is [0, 180].   i.e.  105.3840698 105.2357071 0.218767523 |
| **Corners** | Lat,Long  Fo1  [°] | K-L | The 4 points defined in the following 4 rows represent the intercept of the 4 corner which define the FoV of the instruments with the surface (see Section 2.1).  Their order is defined at SK level. They represent the output of the following SK function:   |  | | --- | | [shape, dref, bsight, bounds] = cspice\_getfov( instr\_id, 4) |   The output bounds represent 4 versor (see *Figure 3*).  Fo1 is the first of these.  Latitude and longitude [°] in the point defined by the intercept between the Fo1 vector and the surface.  i.e.  67.97934992 46.46479814 |
| Lat,Long Fo2  [°] | M-N | Latitude and longitude [°] in the point defined by the intercept between the Fo2 (see Fo1 definition for details) versor and the surface.  i.e.  67.86351053 46.46217652 |
| Lat,Long Fo3  [°] | O-P | Latitude and longitude [°] in the point defined by the intercept between the Fo3 (see Fo1 definition for details) versor and the surface.  i.e.  67.86368617 45.47755838 |
| Lat,Long Fo4  [°] | Q-R | Latitude and longitude [°] in the point defined by the intercept between the Fo4 (see Fo1 definition for details) versor and the surface.  i.e.  67.97952634 45.47522958 |
| **Subnadiral** | Subnad  lat,long [°] | U-V | Latitude and longitude [°] in the point defined by the subnadiral point of the observer  i.e.  67.87817316 45.96884132 |
| Subnad  Dist  [km] | Y | Distance in Km of the subnadiral point respect the observer.  Note that the emission angle has a strong impact on this distance.  i.e.  615.575775884503 |
| **Velocity** | Velocity Bor [km/s] | U | Velocity of the boresight intercept on the surface (see Section 2.1) in km/s  i.e.  2.24729617455818 |
| Velocity Bor Lat  [deg/s] | V | Velocity of the boresight intercept on the surface (see Section 2.1) considering only its Latitudes. The velocity is expressed in ° /s  i.e.  0.0527774076024244 |
| Smearing  (1/4px) [ms] | AF | Smearing time considering a limit of a ¼ of pixel. Smearing time is defined in ms and define the time needed to make the boresight intercept with the surface covering ¼ of pixel in AT direction.  i.e.  0.861445434171591 |
| **Coverage** | Coverage Lat [°] | W | Maximum coverage in latitude which means the maximum difference in latitude between the four corners of the FoV  i.e.  0.116015817385318 |
| Coverage Long [°] | X | Maximum coverage in longitude which means the maximum difference in longitudes between the four corners of the FoV  i.e.  0.989568558788449 |
| Hdir  swath  [km] | AB | Maximum coverage of the instrument in km considering 1 of its columns of the detector. In case of polar orbit and nadir pointing it corresponds the swath AT and it is compatible with the Colverage Lat (W)  i.e.  4.93271214226231 |
| Wdir  swath [km] | AC | Maximum coverage of the instrument in km considering 1 of its rows of the detector.  In case of polar orbit and nadir pointing it corresponds the swath CT and it is compatible with the Colverage Long (W)  i.e.  15.7980244862725 |
| Hdir\_pog [km] | AD | Pixel on ground dimension in the direction of the columns of the detector. In case of polar orbit and nadir pointing it corresponds the pog AT as shown in following figure.  Chart  Description automatically generated  Figure 5 Scheme of the geometric components involved in the SK procedures. In green, the output of the GETFOV which define Fo1,Fo2,Fo3,Fo4; in blue, the SINCPT output  i.e.  0.00770736272228486 |
| Wdir\_pog [km] | AE | Pixel on ground dimension in the direction of the rows of the detector. In case of polar orbit and nadir pointing it corresponds the pog CT.  i.e.  0.00771387914368776 |
| **MTA** | MTA  [°] | AA | Mercury true anomaly of the planet at the epoch of the acquisition. MTA ide defined in a range between [0 360].  i.e.  45.3538693986896 |

# Future improvements

Two main issue are still open in the development of the Simulatotor:

* Extension to known 3d model
* Integration of the radiometric component

For what concert the first point, as explained in Section 6.4, the SOIM for now take advantage of the ellipsoidal approximation of the target body it is an open issue inserting 3D models for targets not supported by spice kernels. Process that is currently applicable for low resolution models only.

The latter point require (for the definition of the integration times ) to define a standard and extensible model for the definition of the optoelectric models of the imaging instruments.

A definition of the target radiometric models is then necessary (it is assumed to develop only the Hapke and Lambertian).

Chart

Description automatically generated

Figure shows examples of possible simulator products.

It is clear that, as explained above, the application for an extended and known target is easily supported by the SKs; however, consider that, in particular for high-resolution cameras, it may be necessary to simulate a single target (in the image a CaSSIS DTM) and its radiometric properties which cannot always be considered uniform. Think of the Hollows on Mercury.

# Competition and criticism

The highly technological nature of planetological research activities requires continuous updating and testing of technologies and solutions, in order to make solutions available to specific problems with low implementation times. All this requires that the funds for training are provided on a constant basis, this would allow to carry out a careful planning of refresher courses, and access to basic research funds in order to acquire experimental equipment, which are not accountable on the funds of project.

The development of these technological experiments is obviously linked to two general criticalities of the project and in particular on its extensibility and dissemination.

Regarding the first point, the SOIM must guarantee its applicability to different imaging tools whether they are under development (e.g., stereo hyperspectral camera - HYPSOS in response to the ASI call for Moon observation; VNIR camera for a mission proposal ASI / JLP for Earth observation) or in full operational phase (as already demonstrated in the case of the Monitornig CAMeras (MCAM) and the STereo Imaging Channel (STC) of the SIMBIO-SYS instrument of the ESA BepiColombo mission and also under study for the High Spatial Resolution Imaging Channel (HRIC) and the Visual near-Infrared Hyperspectral Imanging channel (VIHI) also by SIMBIO-SYS) in order, in the first case, to guide the development of the design towards an optimization of resources and satisfaction of requirements ; in the second case, to monitor the operational capabilities of the instruments over time and possibly provide indications on possible recovery strategies. In this wide-ranging perspective, SOIM must ensure a high adaptability to the implementations of the different types and technologies of the imaging tools to which it is applied and this can only be achieved by taking into account, from the outset, a totally modular tool, an advanced implementation language independent of the development platform and, potentially, the possibility of operating in virtual or simulated environments.

As regards the second criticality, the pipeline requires the dissemination not only of INAF's technology but also of the scientific one as the true user of the products and originator of the requests that the SOIM must respond to. To do this, it is therefore even more necessary to define an architecture and a flow of elaboration, generation and presentation of the products such as to facilitate their visualization and scientific interpretation. A very illustrative example can be the geographical projection in GIS environment of the footprints of a camera during a flyby in order to visualize the portion of the planetary surface observed and therefore obtain information on the observational opportunities as well as their quality in terms of illumination and, potentially , signal-to-noise ratio.