SOIM-User-Manual v 6.0
(Simulator for Operation of Imaging Missions)

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1. Index

Approvation

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2. Introduction

2.1. Scope

This document will describe the Simulator for Operation of Imaging Missions (SOIM) software used to simulate any Imaging System on board of Missions which take advantage of the Spice Kernels (technology).
The document will provide documentation and a description of the input and output files..

2.2. Reference Document

[RD.1]   BC-SIM-TN-002_-_STC_Strategy_Observation

            10.20371/INAF/TechRep/35

[RD.2]   BC-SIM-TN-009_-_STC_GM_Observation_Strategy_Optimization_20220706

            10.20371/INAF/TechRep/173

[RD.3]   BepiColombo MCAM Channels Spice Kernels Optimization

            10.20371/INAF/TechRep/125.

2.3. 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

2.4. Language

The library is currently implemented in MATLAB.

2.5. Software Version

Version 6.0

2.6. Document organization

Section 3 will describe the software, its objectives, and its structure
Section 4 will explain all the input required and their format.
Section 5 will describe all the parameters evaluated and reported in the output.
Sections 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.

3. Software Description

The experience accumulated by INAF in International Space Missions has demonstrated the impact and the scientific return of Imaging tools. In all mission phases, these instruments have required 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 simulating 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.

At the current date the simulator was applied to 5 instruments:
-the three Monitor Cameras (MCAM) on board of BepiColombo Mission
-the CaSSIS camera onboard of ExoMars 2016
-the instrument Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem (SIMBIO-SYS) onboard of BepiColombo mission.

3.1. Objective and structure

Almost all the imaging tools in the planetological field can be modeled as pin-hole tools (definable by a pin-hole model like the classic operation of a dark room). These tools provide images that allow both morphological and radiometric analysis of the bodies of the solar system. However, our group's experience in planetary exploration missions highlighted the lack of an INAF tool to simulate these instruments. Since the earliest stage of design, this tool is essential for the instrument operations 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).
Many of the fundamental parameters of a planetary mission are defined starting from the following inputs:

1) The ephemeris that implies the lighting conditions of the observation scenario
2) the instrument model
3) the model of the target

For missions already in progress, the first is provided directly by the reference agencies as in the standard Spice Kernel (SK) format. In the case of future missions, the tool can integrate the development of the SK with the definition of possible new scenarios.
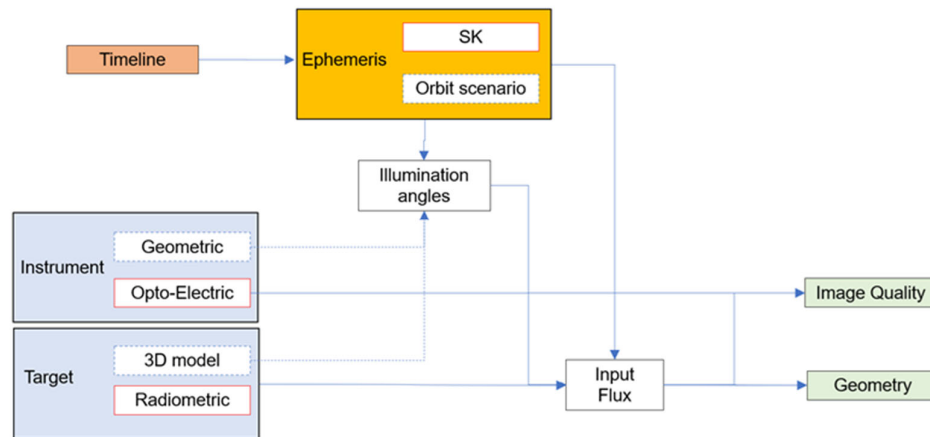
Figure 1 Block diagram for the generation, based on the requested timeline, of the simulation outputs (in green) based on the ephemeris and of the models (in blue). The dashed flows represent the information that can be integrated into the SKs (if absent)

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 a working timeline.

The instrument model is formalized through two sub-models: the geometric one and the optoelectronic one. The first defines the projective system of the chamber. The optoelectronic model represents the sensor's response to the input flow in terms of gain (linked to the filters and the pupil) and dark (or an approximation of it verifiable during the calibration phase). If the geometric model is defined during the calibration phase, the optoelectrical model, which a few parameters can approximate, 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. The target model can be defined generically, for lesser-known bodies, or specifically if it is known from other missions. That's the case of 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 the user to define integration times to avoid saturation or smearing. About the target visibility, in addition to verifying it, it will enable users 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 SIMBIO-SYS channels and used for the study and optimization of the Observation Strategi of VIHI and STC (see [RD.1] and [RD.2]).
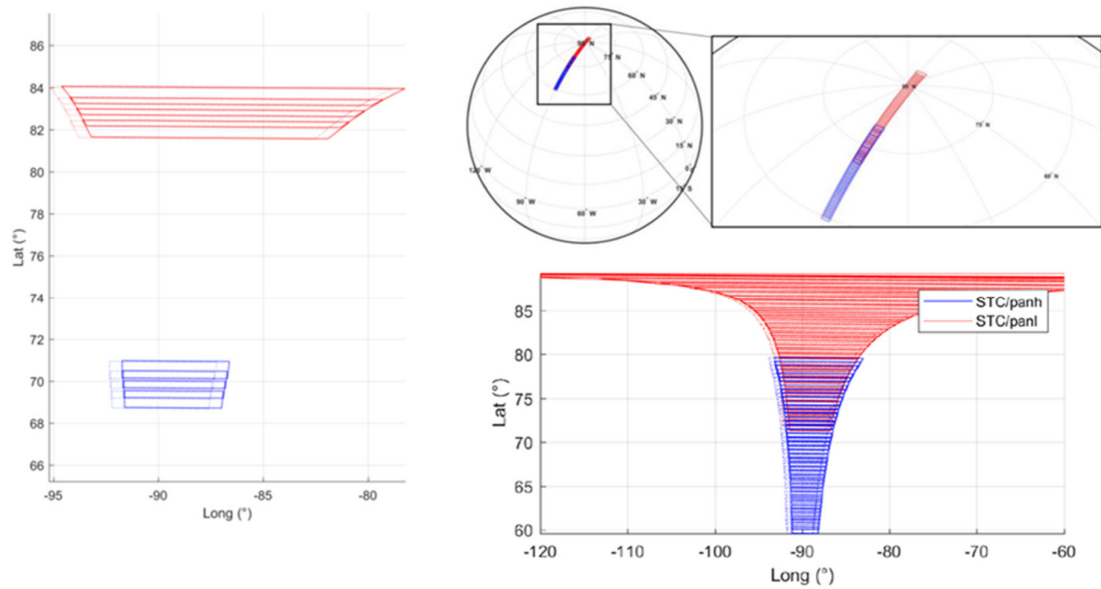
Figure 2 Example of simulator product in the case of polar acquisitions by STC. The two channels (respectively in blue and in red) of the instrument are oriented in a non-nadiral way. The SOIM allows to evaluate on the one hand the repetition time to ensure overlapping between acquisitions; on the other hand, it also provides shapefiles for verifying the target regions actually framed.

For example, with the current simulator version, it was possible, 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 simulation allowed the user to outline the timelines for the acquisitions and validate the geological features taken during these phases.

The user can use a similar process 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.3]).
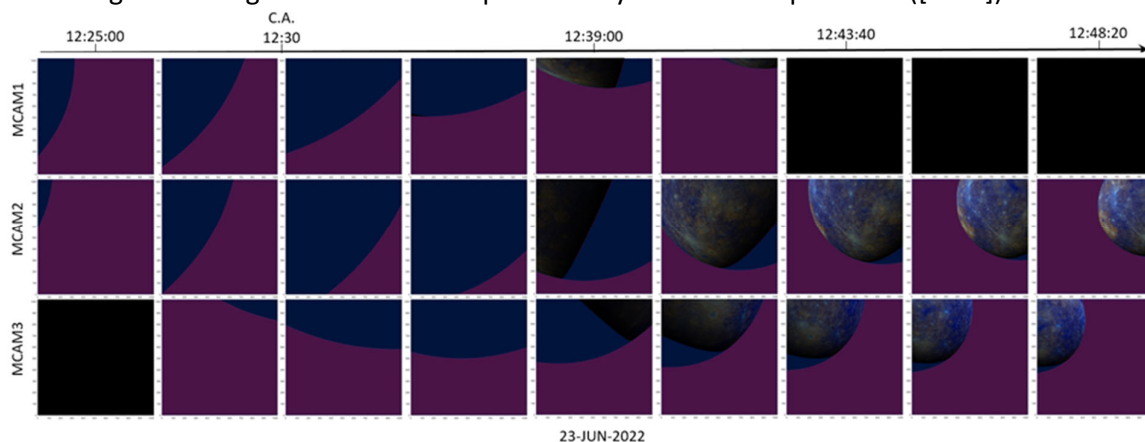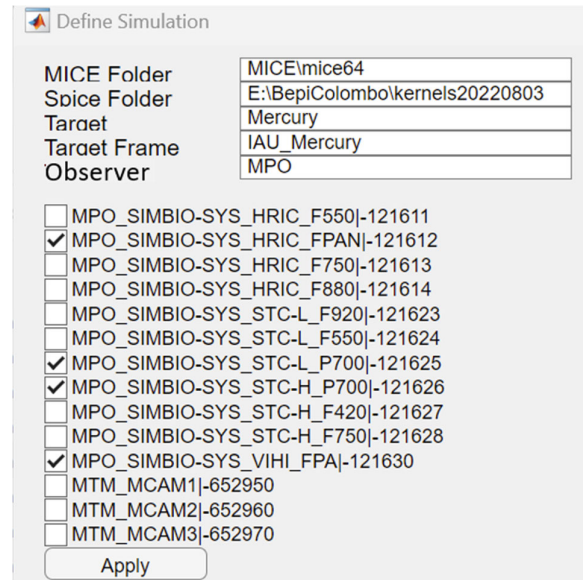

Figure 3 Example of simulator products. In (a) the rendering of the 3 cameras at 5-minute intervals in a neighborhood of the C.A; in (b) a subsection of these images which highlights on the one hand the region concerned and on the other the position of the terminator. In (c) summary of one of these simulations 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.

4. Input

Once run the simulator. It asks for the essential parameters of the simulation, using a form in the Define Simulation Window shown in Figure 4.

Figure 4 define Simulation window showing the main input which can be define.

4.1. Textual

This input includes:
- The Path of Mice folder
- The Path of the spice kernels (the folder must contain an "mk" subfolder with a list of plan files with extension TM. The simulation will consider the most recent)
- The target of the simulation
- The reference frame to be considered
- S/C Observer name

4.2. SK Inputs

From the Define Simulation Window can be selected the Spice kernel IDs. The NAIF IDs currently included in SOIM are reported in Table 1. They represent the most common used Frame kernels by SOIM but additive on can be added extending variable `instruments_id` in "Read_DEFAULT_definitions.m".
NAIF ID refers to the frame kernel of the push broom or push frame camera.

Table 1 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

After clicking the Apply button, a window for selecting the time information file will appear.

4.3. Input timeline file

The input file is a text file that provides the simulation's timing information.
As reported in following example (see Table 2), the TXT file reports in three lines 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 2 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]
```

4.4. Internal option

```
param_method.abcorr='LT+S';
param_method.method='Ellipsoid';
```

5. Output

The output file can be an XLS, XLSX, or CSV file containing all the simulated acquisitions required in the timeline. Each line corresponds to an acquisition, and evaluated parameters are described iin Table 3.
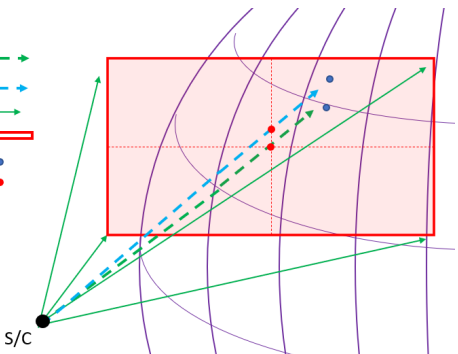
Note that where required it assumed absolute correction defined as `'LT+S'` and intercept method as `'Ellipsoid'.` Different definitions (i.e. dsk 3d model using) will be user accessible in next version of the SOIM.

Table 3 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 channel of SIMBIO-SYS instrument .

Reference Field	Name	Colum	Definition
Time	UTC	A	Acquisition Time in UTC in ISO 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 hours and differently by previous column relative to the beginning of the simulation. i.e. 0
Distances	SurfDist [km]	D	Surface distance in km respects the observer. The surface is as defined in Section 4.4. i.e. 615.575775884503
	Subnad Dist [km]	Y	Distance in km of the subnadiral point respect the observer. Note :the emission angle has a strong impact on the 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 [deg] of the intersection point between the instrument boresight and the surface considered (see Section 4.4) i.e. 67.92225657 45.96994191

Radius Bor [km]	G	Radius of the planet in the intersection point between the instrument boresight and the surface considered (see Section 4.4) i.e. 2439.7	
Phase,Solar,Emiss Bor [°]	H-I-J	the illumination angles in the intersection point between the instrument boresight and the surface. Bot the surface and the aberration corrections considered are defined in Section 4.4: • 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 four corner coordinates of the instrument FoV projection on the surface (see Section 4.4). 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 vectors (see Figure 5). 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) vector 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) vector 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) vector 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	

Velocity	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 Bor [km/s]	U	Velocity of the boresight intercept on the surface (see Section 4.4) in km/s i.e. 2.24729617455818
	Velocity Bor Lat [deg/s]	V	Velocity of the boresight intercept on the surface (see Section 4.4) 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 Coverage 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 Coverage 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.

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

6. Future improvements

Two main issues 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 4.4, 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 requires (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).
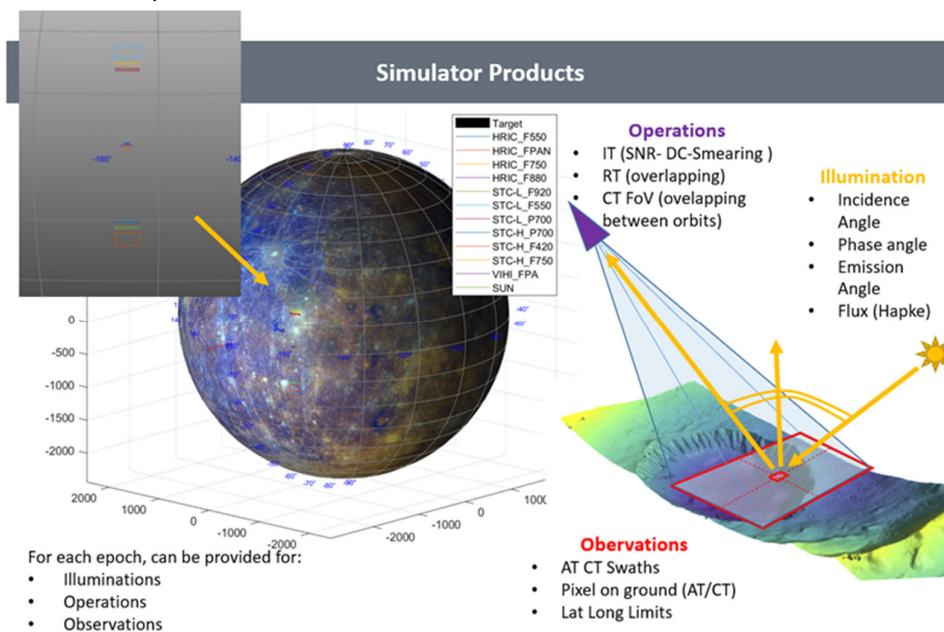

Figure 6 shows examples of possible simulator products.

As explained above, the application to an extended and known target is easily supported by the SKs. However, especially for high-resolution cameras, it may be necessary to simulate a single target (a CaSSIS DTM in the image) and its radiometric properties, which cannot always be considered uniform, like the Mercury's Hollows.

7. Competition and criticism

The highly technical nature of planetological research activities requires continuously updating and testing technologies and solutions. Moreover, it makes solutions available to specific problems with low implementation times. All this requires that the funds for training are provided constantly, and it would allow to carry out of careful planning of refresher courses and access to primary research funds to acquire experimental equipment, which are not accountable to the funds of projects

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

Regarding extensibility, the SOIM must guarantee its applicability to different imaging tools, and some examples are in the operational phase or development. Between the operating instrument, we can mention the Monitoring CAMeras (MCAM) and the STereo Imaging Channel (STC) of the SIMBIO-SYS, both on board the ESA Mission BepiColombo. In addition, it is under investigation the integration of the High Spatial Resolution Imaging Channel (HRIC) and the Visual near-Infrared Hyperspectral Imaging channel (VIHI), also in the SIMBIO-SYS suite.

As an example of missions at the first stage that can take advantage of the SOIM tool, we can mention the stereo hyperspectral camera - HYPSOS in response to the ASI call for Moon observation; VNIR camera for a mission proposal ASI / JLP for Earth observation.

 In this wide-ranging perspective, SOIM must ensure high adaptability to the implementations of the different types and technologies of the imaging tools to which it is applied. We achieved this objective by building modular software, platform-independent and, potentially the possibility of operating in virtual or simulated environments.