CASSIS EXPERIMENT OPERATIONS PLAN (EOP)

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	Name	Signature	Date
Prepared by	Ruth Ziethe Project Manager	Ruth Ziethe	21 | 07 | 2015
Approved by	Nicolas Thomas Principal Investigator		21 | 07 | 2015

DOCUMENT CHANGE RECORD

Issue	Revision	Date	Pages, Tables, Figures affected	Modification	Initials
0	1	09 Aug 2013	All	New Document	RZ
0	2	15 Sep 2013		State Diagram added	RZ
0	3	20 Sep 2013		Title changed	RZ
0	4	7 Feb 2014	All	Major update	NT
0	5	03 Apr 2014	All	More updates	NT
0	6	12 Jun 2014	Section 9	DELETED	RZ
			Section 9	(after former section 9 was deleted) updated …	NT
0	7	18 Sept 2014	Section 9	Modified stellar calibration text to indicate that all will be done in cruise.	NT
1	0	14 Nov 2014		Signatures for CDR	RZ
1	1	09 Dec 2014	Section 11.1	Updated table with monitoring values for PT1000 temperatures provided by S/C	RZ
		13 Jan 2015	Page 26	Updated the along-track targeting error requirement	RZ
			Page 15 section 4.2	Updated Cruise check-outs	RZ
			Page 19 section 7	Updated timing info on science commissioning	RZ
			Section 12	Removed (emergency mode)	RZ
			Page 8 section 2.2	Updated telescope orientations for launch and cruise	RZ
1	2	21 7 2015	8.2	Deleted TBC	RZ
			8.2.3.1	Deleted TBC	RZ
			12.2	Deleted TBC	RZ
			8.8	Completed Operations scheduling chapter	RZ
			14	DELETED	RZ

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List of documents

Applicable documents		
AD01	EXM-PL-IRD-ESA-00003 Issue 2 Rev 0 TGO E-IRD (JCCB - Signed)	Experiment Interface Requirements Document
AD02	EXM-OM-TNO-AF-0627-02	Exomars Mission Parameters for TGO Design

Reference documents		
RD 01	EXM-CA-LIS-UBE-00001	List of Acronyms Iss 1 Rev 0
RD 02	EXM-CA-TNO-UBE-00003	In Flight Calibration Iss 1 Rev 2
RD 03	EXM-CA-UMA-UBE-10001	CaSSIS FOUMA Iss 0, Rev 4

Scope of the Document

This document describes the operation of the CaSSIS instrument onboard the ExoMars Trace Gas Orbiter spacecraft in flight, from cruise to commissioning and imaging in Mars orbit.

1 Introduction

1.1 Instrument description

The ESA ExoMars program consist of two stages: an orbiter (called Trace Gas Orbiter, TGO) to be launched in 2016 and a rover to be launched in 2018. The program will demonstrate key flight and in situ enabling technologies by searching for signs of past and present life on Mars, investigate the water/geochemical environment and atmospheric trace gases and their sources. The TGO will carry a camera called CaSSIS (Colour and Stereo Surface Imaging System) developed by the University of Bern, which will take high resolution stereo images in 4 colours of the Martian surface. This imager will characterize sites which have been identified as potential sources of trace gases and investigate dynamic surface processes and thus certify potential future landing sites. CaSSIS will observe a 8 km wide swath thereby providing the best colour imaging acquired from Mars, so far.

CaSSIS is made out of two major units: Camera Rotation Unit (CRU) and Electronics Unit (ELU). Figure 1 illustrated the concept. The CRU comprises of the telescope (incl. focal plane and associated electronics), the rotation system, cable management system and some structure to support all of the above and mount the CRU to the spacecraft. The ELU contains the boards with the electronics required to operate the camera.

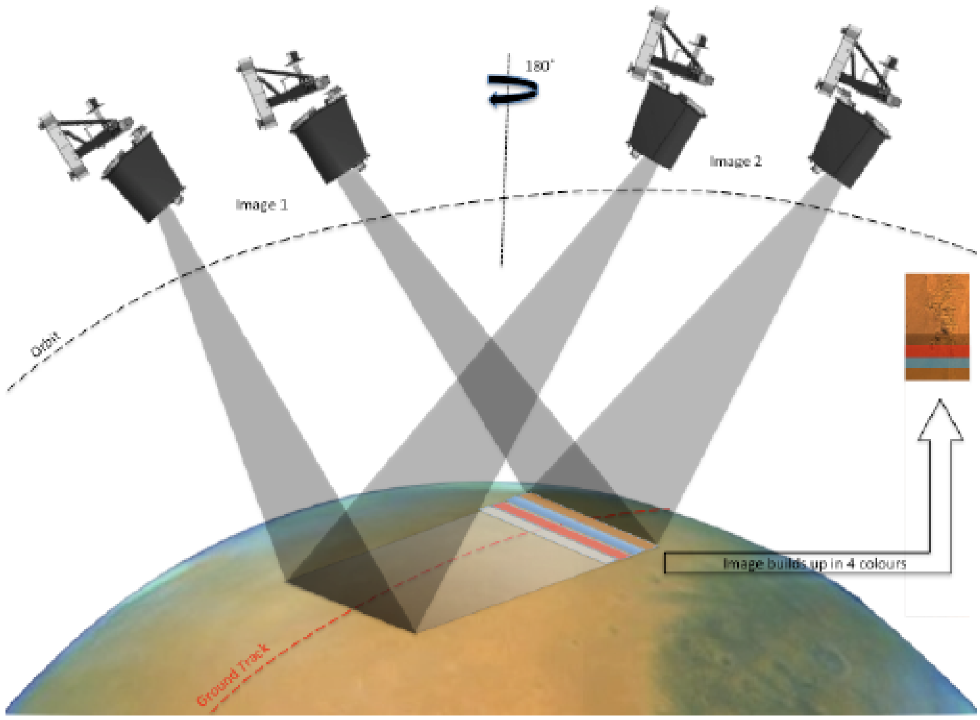


Figure 1: CaSSIS Stereo Image Acquisition

2 DEFINITIONS

2.1 Imaging nomenclature

The following definitions of "images" shall be used throughout.

Term	Definition
Detector Frame	The full detector area shall be referred to as the detector frame.
Exposure	Each individual exposure of the 2048 x 2048 array shall be referred to as an exposure.
Sub-exposure	Each sub-array of the exposure shall be referred to as the sub-exposure. This is appropriate for each individual colour sub-array acquisition.
Exposure sequence	CaSSIS shall acquire N sub-exposures in a sequence following a single command on the mission timeline.
Image	The full exposure sequence shall be referred to as an image.
(Nominal) stereo pair	When two images are acquired of the same target on the same orbit by rotating the telescope, this shall be described as a (nominal) stereo pair
Non-nominal stereo pair	When two images are acquired of the same target on different orbits by whatever means, this shall be described as a non-nominal stereo pair

2.2 Telescope default orientations

2.2.1 Default zero position of the rotation mechanism

The default (zero) position of the instrument rotation mechanism is shown in the following figure. The default (zero) position is with the telescope pointing 10 degrees towards the +y axis. This will be the position the CRU is integrated onto TGO.

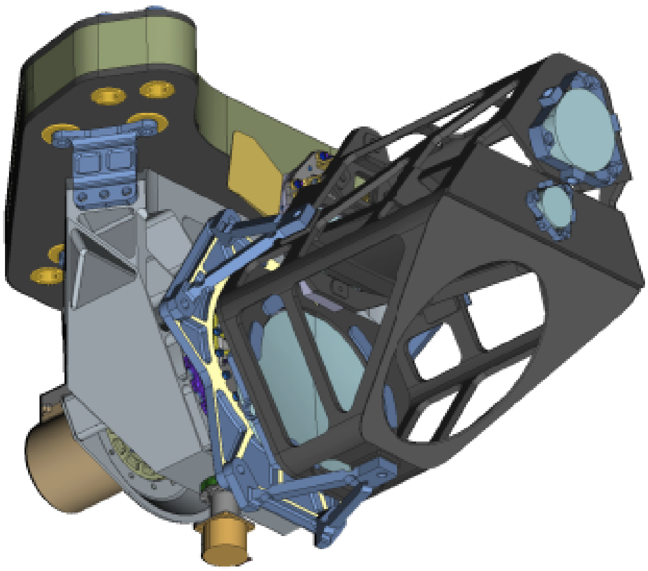


Figure 2: Telescope default (=launch) position.

2.2.2 Launch position

CaSSIS shall be launched in the default (zero) position. That way the large aperture is less likely to catch depris shaken loose during launch vibrations.

2.2.3 Thermal optimization position (cruise)

Recent work has shown that there may be an optimum position to turn the telescope to for survival power reasons. This is still in work but this position will NOT be the default (zero) position. Operations should account for a turn of the telescope after near-Earth commissioning to this optimum position for the inter-planetary cruise phase of the mission.

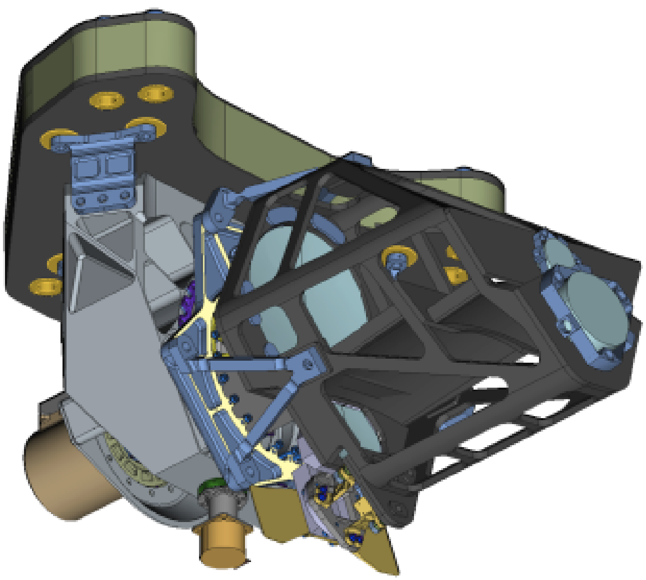


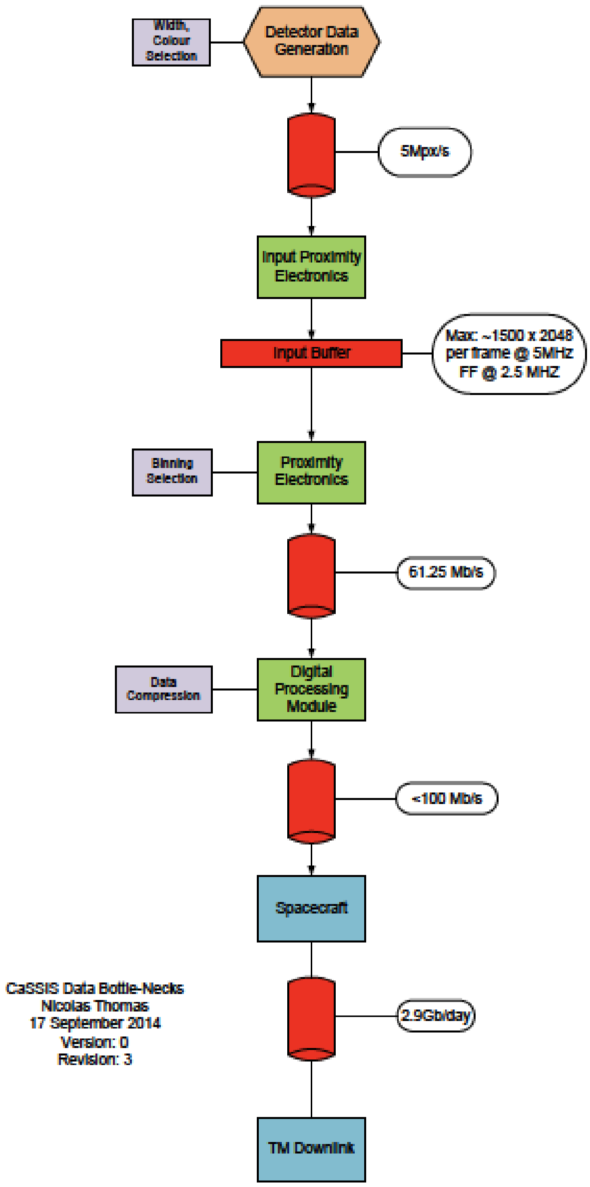
Figure 3: Telescope in cruise position

3 Building Blocks

3.1 Scientific imaging

3.1.1 Instrument internal data bottlenecks

The CaSSIS system is running the focal plane sub-system at a high speed. There are internal bottlenecks for data transfer within the system. These are summarized in the following figure.



The time between exposures is typically 360 ms and hence a maximum of 5 Mpx/s x 0.36 s pixels can be read from the detector in one exposure. This implies that either the maximum number of colours or the maximum swath width can be used but not both simultaneously.

The rate of data transfer between the proximity electronics and the DPM is controlled by the SpaceWire data transfer rate which is not fully known at this time but is a minimum of 61.25 Mbit/s (the maximum is likely to lie between 70 and 80 Mbit/s). The FPS can bin the data at this point to reduce the data transfer rate but this will be limited by the buffer size in the proximity electronics although this limit is not yet established.

CaSSIS will circumvent these limitations via commanding. We will use the following nomenclature.

- Basic structures are the full swath width but with various colour lines and binning
- Reduced structures are reduced swath widths (nominally 1536 pixels) but with various colour lines and binning.

For a stereo pair, 2 basic and/or reduced structures will be combined to form the stereo pair.

3.1.2 Basic structures

Image acquisition of science targets shall be built from the following default exposure structures.

Table 1 Basic building blocks from which image swaths will be created. The swath width in pixels is here 2048 pixels in all cases. Blocks where the acronym is red are currently thought to be incompatible with the timing of the hardware. This however requires detailed verification at system level.

Exposure structure	Acronym	Uncompressed Data Volume Per Frame [Mbit]
Pan 1 x 1	PAN1	7.34
2 Colour	CL21	14.68
3 Colour	CL31	22.02
Pan 1 x 1; 1 Colour 1 x 1	PAN1CL11	14.68
Pan 1 x 1; 2 Colour 1 x 1	PAN1CL21	22.02
Pan 1 x 1; 3 Colour 1 x 1	PAN1CL31	29.36
Pan 1 x 1; 1 Colour 2 x 2	PAN1CL12	14.68
Pan 1 x 1; 2 Colour 2 x 2	PAN1CL22	22.02
Pan 1 x 1; 3 Colour 2 x 2	PAN1CL32	29.36

3.2 Reduced swath widths

Table 2 Basic building blocks with data volumes for a reduced swath width (here = 1536 pixels). Structures which are currently incompatible with the instrument timing have red acronyms.

Exposure structure	Acronym	Uncompressed Data Volume Per Frame [Mbit]
Pan 1 x 1	PAN1T	5.51
2 Colour	CL21T	11.01
3 Colour	CL31T	16.52

Exposure structure	Acronym	Uncompressed Data Volume Per Frame [Mbit]
Pan 1 x 1; 1 Colour 1 x 1	PAN1CL11T	11.01
Pan 1 x 1; 2 Colour 1 x 1	PAN1CL21T	16.52
Pan 1 x 1; 3 Colour 1 x 1	PAN1CL31T	22.02
Pan 1 x 1; 1 Colour 2 x 2	PAN1CL12T	11.01
Pan 1 x 1; 2 Colour 2 x 2	PAN1CL22T	16.52
Pan 1 x 1; 3 Colour 2 x 2	PAN1CL32T	22.02

3.3 Stereo combinations

Table 3 Potential combinations of basic and reduced structures to produce stereo pairs. The data volumes can be computed from the individual structures.

Exposure structure	Acronym
PAN1 + PAN1	PAN1_PAN1
PAN1 + PAN1CL11	PAN1_PAN1CL11
PAN1 + PAN1CL21	PAN1_PAN1CL21
PAN1 + PAN1CL31	PAN1_PAN1CL31
PAN1 + PAN1CL12	PAN1_PAN1CL12
PAN1 + PAN1CL22	PAN1_PAN1CL22
PAN1 + PAN1CL32	PAN1_PAN1CL32
PAN1T + PAN1T	PAN1T_PAN1T
PAN1T + PAN1CL11T	PAN1T_PAN1CL11T
PAN1T + PAN1CL21T	PAN1T_PAN1CL21T
PAN1T + PAN1CL31T	PAN1T_PAN1CL31T
PAN1T + PAN1CL12T	PAN1T_PAN1CL12T
PAN1T + PAN1CL22T	PAN1T_PAN1CL22T
PAN1T + PAN1CL32T	PAN1T_PAN1CL32T
PAN1CL11+PAN1CL11	PAN1CL11_PAN1CL11
PAN1CL11+PAN1CL21	PAN1CL11_PAN1CL21
PAN1CL11+PAN1CL31	PAN1CL11_PAN1CL31
PAN1CL11+PAN1CL12	PAN1CL11_PAN1CL12
PAN1CL11+PAN1CL22	PAN1CL11_PAN1CL22
PAN1CL11+PAN1CL32	PAN1CL11_PAN1CL32
PAN1CL12+PAN1CL12	PAN1CL12_PAN1CL12
PAN1CL12+PAN1CL22	PAN1CL12_PAN1CL22
PAN1CL12+PAN1CL32	PAN1CL12_PAN1CL32

3.4 Total data volume control

The number of frames in an exposure sequence and the compression ratios will be selected to match the available data volume.

3.5 Testing

The following exposures will be used for testing purposes.

Table 4 Additional basic building blocks from which test sequences will be created

Exposure structure	Acronym	Uncompressed Data Volume Per Frame [Mbit]
Full-exposure (2048 x 2048)	FF1	58.72
Ghost exposure (1508 x 2048)	GF1	43.24
Dark exposure (256 x 2048)	DF1	14.68

Although it might appear from the above that these sub-exposures cannot be read-out, it is important to recognize that the frequency of the read-out can be lowered making it possible to read-out the full detector as long as the repetition frequency berween exposures is low. For test/calibration purposes this should always be the case.

The read-out of the detector to the proximity electronics can support three read-out speeds as shown in the following table.

Table 5 Allowed read-out frequencies. Note that ROIC frequency can be selected via the WriteAddress command to the proximity electronics

Allowed frequency [MHz]	Comment
5	Nominal
2.5	Test
1.25	Not currently foreseen

4 Cruise

4.1 Near-Earth commissioning

This is assumed to be the first switch-on of the CaSSIS instrument after launch. We request this to be no earlier than 5 days post-launch.

[CAS-EOP-0010] During first switch-on of CaSSIS, the spacecraft shall be fixed pointed such that the CaSSIS boresight is pointed at a CaSSIS in-flight calibration target (see EXM-CA-TNO-UBE-00003) when CaSSIS is in its default position.

Table 6: Requirements for Near-Earth Commission Phase

Requirement	Description	Comment
	It is desirable that spacecraft fixed points the CaSSIS boresight at a CaSSIS in-flight calibration target (see EXM-CA-TNO-UBE-00003) with CaSSIS in the position in which it was last switched-off (thermal survival power optimization position).	
	Power on, health check, CaSSIS in SAFE MODE, download of HK data	
	Check of CONFIG mode, download of HK data	Modify selected parameters, repeat for characteristic parameter sets
	Check of LOW POWER STANDBY mode, download of HK data	
	HEAT UP and switch to STANDBY, download of HK data	
	Check MOTOR HOMING, download of HK data	
	Check IMAGE mode (single), download of HK data, download science data	Verify star on detector if pointing request has been accepted
	Check ROTATE TO IMAGE POSITION, download of HK data	
	Check IMAGE mode (stereo; including 180 deg image rotation), download of HK data, download science data	
	Check of data transmission to Earth	Transmission of all data generated in checks mentioned

Requirement	Description	Comment
		above
	Check of data processing on Earth	Test entire data line from Ground Station to systematic processing of science data and distribution of results

4.2 Cruise check-outs

During in-Cruise check-out CaSSIS will be pointing at star fields in the nominal TGO orientation ((see EXM-CA-TNO-UBE-00003). This would be an opportune time to carry out the calibration.

Table 7: Requirements for Cruise check-out

Requirement	Description	Comment
	It is desirable that spacecraft fixed points the CaSSIS boresight at a CaSSIS in-flight calibration target (see EXM-CA-TNO-UBE-00003) with CaSSIS in the position in which it was last switched-off (thermal survival power optimization position).	
	Power on, health check, CaSSIS in SAFE MODE, download of HK data	
	Check of CONFIG mode, download of HK data	Modify selected parameters, repeat for characteristic parameter sets
	Check of LOW POWER STANDBY mode, download of HK data	
	HEAT UP and switch to STANDBY, download of HK data	
	Check IMAGE mode (single image) download of HK data, download science data	
	Check MOTOR HOMING, download of HK data	
	Check ROTATE TO IMAGE POSITION, download of HK data	
	Check IMAGE mode (stereo; including 180 deg rotation), download of HK data, download science data	

Requirement	Description	Comment
	Check of data transmission to Earth	Transmission of all data generated in checks mentioned above
	Check of data processing on Earth	Test entire data line from Ground Station to systematic processing of science data and distribution of results

5 Orbit Injection Imaging

CaSSIS will support project objectives for imaging during MOI on a best effort basis.

CaSSIS requests imaging immediately after orbit injection prior to aerobraking.

[CAS-EOP-0070] CaSSIS requests that a dataset is obtained during the pre-aerobraking phase (after MOI).
Verification: R
Level: System
Info: This will allow us to exercise our procedures for ground processing and check for errors in our exact commanding. It should be noted that HiRISE on MRO did this and discovered bugs in commanding during this phase that were fixed before the prime mission started saving several weeks.

Info: The duration of this imaging is not a significant schedule driver. We expect all necessary to be acquired in <= 2 orbits.

6 AEROBRAKING

CaSSIS is prepared to support imaging during the aerobraking phase when opportunities allow and when project objectives for imaging are identified.

CaSSIS places no specific requirements on this phase.

7 Science Commissioning

We assume that commissioning of the instrument will take place at the beginning of the Science Phase once the TGO is in the science orbit around Mars.

Table 8: Requirements for Science Commissioning Phase

Requirement	Description	Comment
	Spacecraft is assumed to be nadir-pointing	
	Power on, health check, CaSSIS in SAFE MODE, download of HK data	
	Check of CONFIG mode, download of HK data	Modify selected parameters, repeat for characteristic parameter sets
	Check of LOW POWER STANDBY mode, download of HK data	
	HEAT UP and switch to STANDBY, download of HK data	
	Check IMAGE mode download of HK data, download science data	Target shall not be specified, data acquisition over the dayside of Mars at a random target
	Check MOTOR HOMING, download of HK data	
	Check ROTATE TO IMAGE POSITION, download of HK data	Here we go to align the instrument correctly with the ground-track
	Check IMAGE mode (stereo), download of HK data, download science data	Target shall not be specified, data acquisition over the dayside of Mars at a random target
	Check of data transmission to Earth	Transmission of all data generated in checks mentioned above
	Check of data processing on Earth	Test entire data line from Ground Station to systematic processing of science data and distribution of results

8 In-Orbit Science Operations

CaSSIS will be the main imager on the TGO spacecraft and deliver high resolution stereo and single images from the Martian surface in up to four colours. The major science investigations of CaSSIS are:

- characterize sites which have been identified as potential sources of trace gases
- investigate dynamic surface processes (e.g. sublimation, erosional processes, volcanism) which may contribute to the atmospheric gas inventory
- certify potential future landing sites by characterizing local slopes, rocks, and other potential hazards.

CaSSIS will observe a swath (>8 km wide) in colour thereby providing the best colour imaging acquired from Mars, so far. It will have excellent stray light rejection and essentially identical photometric angles and path lengths through the Martian atmosphere for each colour band. The 5 m/pixel colour imaging will improve mapping and interpretation of mineral units identified by spectrometers. Stereo imaging is accomplished by use of a rotation drive which will rotate the optics through 180° to acquire 2 images with 20° convergence on one pass (**Error! Reference source not found.**). The resulting Digital Terrain Models (DTMs) will enable stratigraphic measurements and identification of surface roughness for landing site certification.

8.1 Mars parameters

In Mars' basic properties relevant for CaSSIS measurements are listed.

Table 9: Mars Parameters

Mass	6.45×10^{23} kg
Radius	3394 km
Density	3940 kg cm^{-3}
Semi-major axis	227.95×10^{6} km
Surface gravity	3.74 m^{-2}
Surface area	1.45×10^{14} m^{2}
Visual geometric albedo	0.15
Geometric albedo at 550 nm	0.12
Rotation period	1.026 d
Orbital period	687 d
Eccentricity	0.0934
Perihelion distance	1.39 AU
Aphelion distance	1.67 AU
Escape velocity	5.04 km s^{-1}
Solar flux at 1AU	1383 W m^{-2}
Solar flux at perihelion	719 W m^{-2}

Mass	6.45×10^{23} kg
Solar flux at aphelion	498 W m^{-2}
Colour change	25 % 100 nm^{-1}

8.2 TGO Orbit

The selected orbit for the science mission of ExoMars has the following parameters :

- Quasi Circular orbit of about 120min duration (eccentricity range 4×10^{-3} to 10^{-2} over the science mission phase, the argument of periaspis (ω) ranging from 250 to 290 degrees.
- Semi major axis is about 3802 km leading to a mean orbit altitude of 405 km above Mars equatorial radius.
- Inclination varies from 73,62 to 73,72 deg over the science mission phase.

The following points are important for CaSSIS.

8.2.1 Eccentricity effects

The timing between exposures depends on the ground-track velocity. Overlap between frames must be guaranteed. The slightly eccentric orbit of TGO must therefore be taken into account when planning the observing sequence and will control whether a particular observing structure can be executed within the CaSSIS FPS.

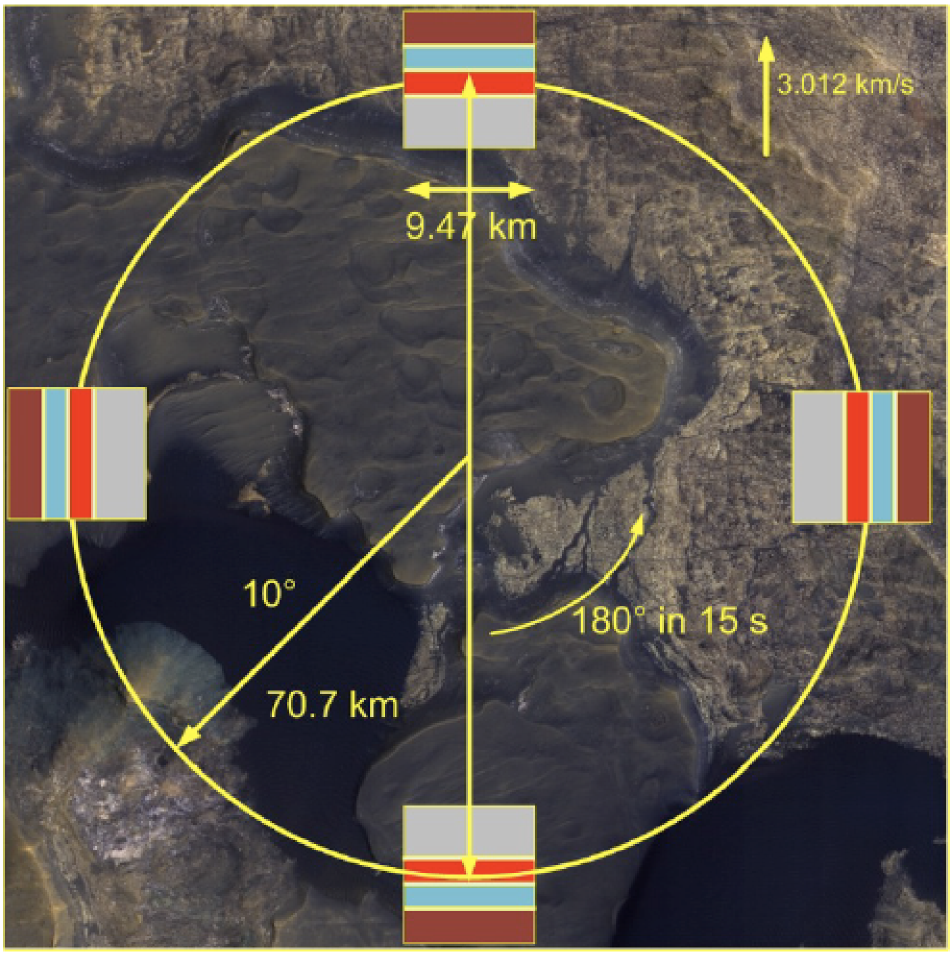
8.2.2 Topography effects

From an altitude of 400 km, the topography of Mars is not negligible and must be taken into account when planning the observing sequence and will control whether a particular observing structure can be executed within the CaSSIS FPS.

8.2.3 Effect of the resonant orbit

8.2.3.1 *Background*

CaSSIS has a rotation mechanism which allows it to point 10 deg along-track in front of the spacecraft and 10 deg along track behind the spacecraft. The combination of these two views produces a stereo image. The system is a push-frame camera with 4 coloured filters covering the detector. As illustrated in the figure below, the rotation mechanism will point the field of view of CaSSIS to the left and the right of the ground-track but the colour strips will no longer be orthogonal to the spacecraft motion.



In the extreme case, when the rotation mechanism is at 90 deg to the ground-track, the individual colour sub-exposures never cross. Hence, we cannot build either a stereo pair nor a colour image of a target. To alleviate this problem and hit a target off the ground-track, a spacecraft roll is needed.
A second issue arises from orbit inaccuracies. Target scheduling will be planned a few weeks before execution (as described in the Mission Planning Concept Document) and the exact timing and pointing parameters will be defined using a long term reference trajectory. However due to the unpredictable orbit phasing errors, the time accuracy of this trajectory will have an uncertainty (tens of seconds, to be evaluated later in the program with MOC involvment), which would imply a shift in the time of the observation and the final targeting coordinates due to the Mars rotation. The timing issue may be partially solved by the planning system by using relative times with respect to the equator, thus correcting latitudinal along-track errors. However the issue of the longitudinal cross-track error remains a major concern due to the Mars rotation speed (~240m/s at the equator, i.e. >2km error for a time shift of 10seconds). In order to correct this issue and point to the right longitude, the planning system shall be able to update the pointing parameters at short term and the spacecraft shall be able to cope with enough cross-track angle so as to be able to point to the originally planned target. Details for maximum range of cross-track angles will have to be defined depending on the limitations on the stereo image reconstruction and the constraints on spacecraft pointing.

8.2.3.2 *Spacecraft Orbit Repeat Cycle*

ESOC is currently proposing repeat cycles for the orbit. The original proposal was a repeat cycle of around 5 days and is currently around 35 days. It should be noted that if CaSSIS remains nadir-pointed only and the repeat cycle is executed perfectly, then CaSSIS will never be able to view certain areas on the surface. This is particularly problematic if future landing sites are to be mapped or current landing sites are to be monitored.

The inability of CaSSIS to view and map landing sites violates one of our level 1 science requirements.

We request that ESA investigates the capability of the spacecraft to roll in order to fill-in coverage and thereby allow targeted observations.

In the following table, we show how the repeat cycle is linked to the magnitude of the spacecraft roll needed to allow full coverage of the surface. (We ignore the fact that the spacecraft has an orbit inclination of 74 deg and therefore cannot view targets at latitudes larger than 74 deg. We look here only at low latitude targets.)

The table calculates the distance between ground-tracks using a given orbit repeat cycle. For a spacecraft roll given in the left column, it is computed whether the "gap" between ground-tracks can be filled-in or not. The possible swath width which could be covered by CaSSIS using the given spacecraft roll is given in the 2nd column.

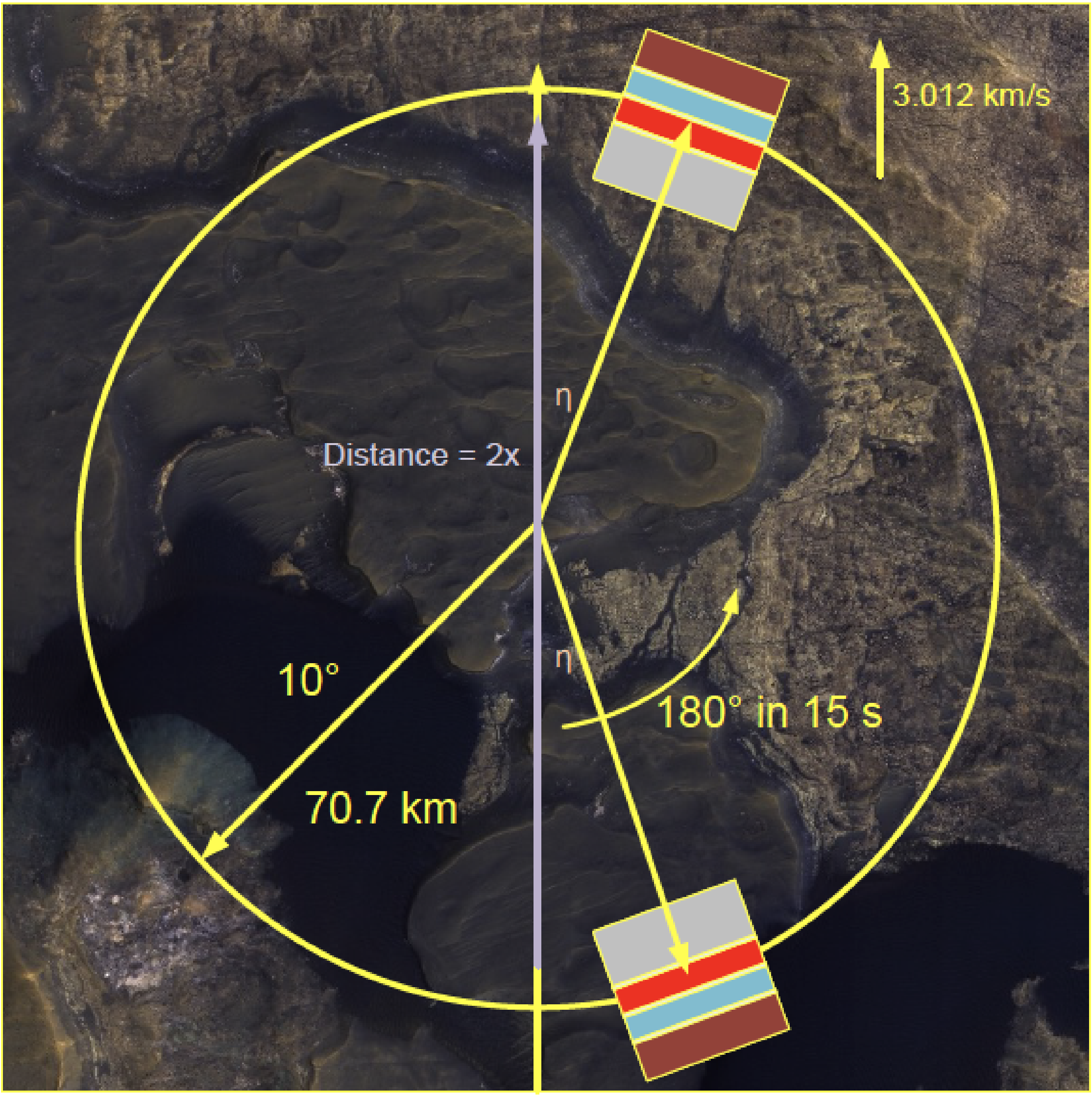
For a repeat cycle of 5 days (the previous baseline), the spacecraft would have needed to roll at least 18 deg to hit a target (if that target was exactly in the middle between 2 ground-tracks). For the current baseline of about 35 days, we can see that a roll of 3 deg should be sufficient.

		Days to repeat [day]										
		5	7.5	10	12.5	15	17.5	20	25	30	35	40
	Ground-track spacing [km]	349.59	234.34	174.80	140.30	116.53	100.12	87.40	69.92	58.27	49.94	43.70
Spacecraft tilt [deg]	Swath coverage [km]	Compliance										
0	9.31	0	0	0	0	0	0	0	0	0	0	0
1	23.27	0	0	0	0	0	0	0	0	0	0	0
2	37.23	0	0	0	0	0	0	0	0	0	0	0
3	51.19	0	0	0	0	0	0	0	0	0	1	1
4	65.16	0	0	0	0	0	0	0	0	1	1	1
5	79.12	0	0	0	0	0	0	0	1	1	1	1
6	93.08	0	0	0	0	0	0	1	1	1	1	1
7	107.04	0	0	0	0	0	1	1	1	1	1	1
8	121.01	0	0	0	0	1	1	1	1	1	1	1
9	134.97	0	0	0	0	1	1	1	1	1	1	1
10	148.93	0	0	0	1	1	1	1	1	1	1	1
11	162.90	0	0	0	1	1	1	1	1	1	1	1
12	176.86	0	0	1	1	1	1	1	1	1	1	1
13	190.82	0	0	1	1	1	1	1	1	1	1	1
14	204.78	0	0	1	1	1	1	1	1	1	1	1
15	218.75	0	0	1	1	1	1	1	1	1	1	1
16	232.71	0	0	1	1	1	1	1	1	1	1	1
17	246.67	0	1	1	1	1	1	1	1	1	1	1
18	260.63	0	1	1	1	1	1	1	1	1	1	1

This calculation assumes a circular orbit and does not account for pointing errors (e.g. APE). Hence, we request that a minimum spacecraft roll of +/- 5 deg be investigated to ensure that fill-in between ground-tracks can be executed.

8.2.3.2.1 Slight off-pointing using the rotation mechanism

While using the rotation mechanism is not the best way to provide fill-in between ground-tracks, there may be a requirement to correct orbit errors at the last minute. The rotation mechanism allows some flexibility but at cost as is shown in the next figure.



A stereo pair can be created even if the target is slightly off the ground-track. However, this has three major disadvantages.

- The time between the two stereo images is reduced thereby reducing the margin on the time available for the rotation
- The swath width is reduced by the cosine of the rotation angle and colour filter overlap is reduced
- The correction for stitching the images becomes more complex.

Hence, this is considered as a last resort for correcting errors. The following table notes our targeting requirements.

Requirement	Quantity	Comment
Cross-track targeting error requirement	2 km	To be corrected by roll to this accuracy taking into account orbit error AND spacecraft errors.
		Corresponds to ~22% of the swath width
Along-track targeting error requirement	5 km	This is merely a timing error for image execution and can be compensated by CaSSIS lengthening its swath. This takes into account orbit error AND spacecraft errors (*1)
		Corresponds to an additional 4 sub-exposures in the CaSSIS operation sequence = 10% more data.
Minimum spacecraft roll requirement	+/- 5 deg from nadir	To ensure all point with +/-74 deg latitude can be targetted
APE (cross-track)	0.54 km	Assumed spacecraft contribution to cross-track targeting error
APE (along-track)	1.35 km	Assumed spacecraft contribution to along-track targeting error.
AME	1.05 km	Spacecraft pointing knowledge after the fact
RPE (short-term)	2.5 m	Short-term (0.5 s) jitter

(*1) CaSSIS understands that this along track prediction error requirement is more stringent that what the S/C can do. So far MAROD-45 in FD RC specifies 10 km over 12 days.
However, by lengthening the swath the 10km value can be improved already.
Additionally CaSSIS can calibrate the S/C's 3 second error along-track assuming that CaSSIS we can optimise the starttime of the image acquisition as part of the short term plan.

8.2.4 Effect of the inclination

The inclination of the selected orbit is a serious constraint on the study of polar processes. Clearly, nadir pointed observations would only allow observations of latitudes up to 74 deg. Rolling the spacecraft near its maximum latitudes will provide some additional science.

[CAS-EOP-0040] CaSSIS requests evaluation of the maximum roll angle feasible to allow near-polar imaging.
Verification: R

8.3 Planning Approach

Our approach to meeting the ESAC planning cycle is shown in the following figure. Dates and timings are still to be agreed.

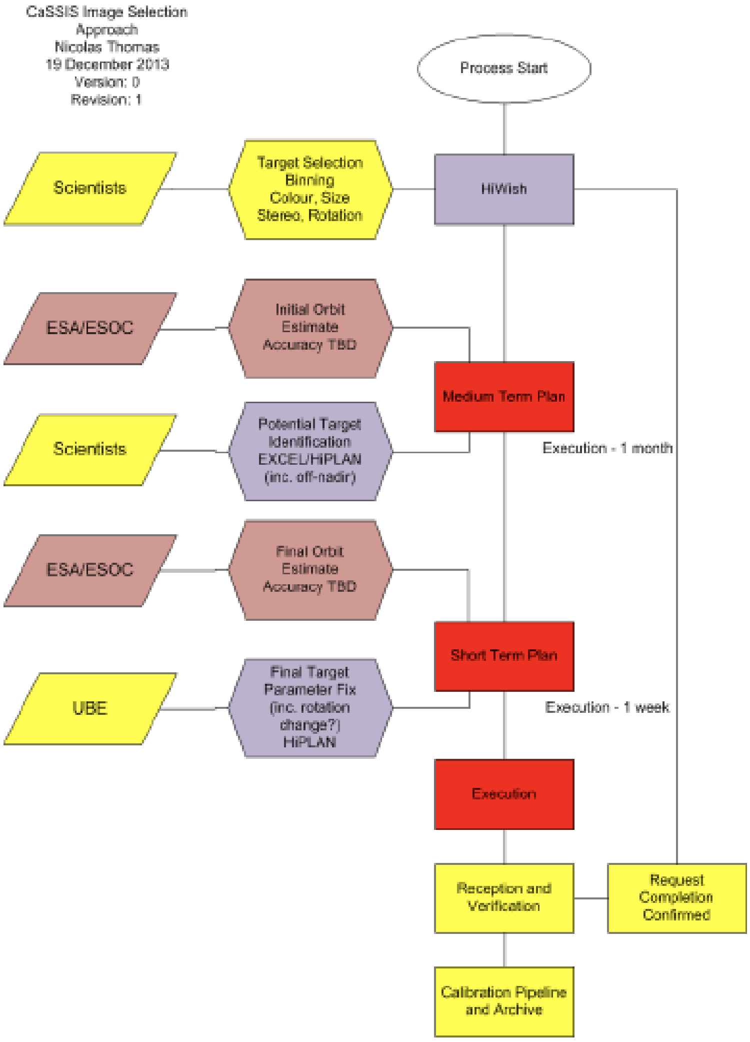


Figure 4 Image selection approach

8.4 Long-Term Planning

8.4.1 General Philosophy

In general, we assume that CaSSIS will be able to acquire one stereo image and one non-stereo image per orbit. This may be reduced (i.e. to one stereo or one non-stereo or indeed no image at all on one orbit) depending upon data volume constraints and target availability.

CaSSIS expects one pointed (targetted) image per orbit. If a second image is taken in one orbit, it is assumed that this image will be with no spacecraft yaw steering (i.e., no fixed nadir pointing) and with the spacecraft nadir pointing. For the acquisition of the single image Routine Nadir Pointing is assumed. In Mars-orbit commissioning may well establish that different pointing modes are to be used.

The next sections show the image acquisitions for an average case, a case with low data volume per day, and a case with high data volume per day.

8.4.2 Average

It is assumed that, on average 2900 Mbit/day has been allocated to CaSSIS. A typical plan for the images to be acquired in a one day period is shown in the following table.

Acronym	ID	No. of images per day	Number of frames	Compression ratio	Data volume [Mbit/day]
Basic Structures					
PAN1	1		40	6	0.0
CL21	2		40	6	0.0
CL31	3		40	6	0.0
PAN1CL11	4		40	6	0.0
PAN1CL21	5		40	6	0.0
PAN1CL31	6		40	6	0.0
PAN1CL12	7		40	6	0.0
PAN1CL22	8	8	40	6	587.2
PAN1CL32	9		40	6	0.0
Reduced Structures					
PAN1T	10		40	6	0.0
CL21T	11		40	6	0.0
CL31T	12		40	6	0.0
PAN1CL11T	13		40	6	0.0
PAN1CL21T	14		40	6	0.0
PAN1CL31T	15	4	40	6	587.2
PAN1CL12T	16		40	6	0.0

Acronym	ID	No. of images per day	Number of frames	Compression ratio	Data volume [Mbit/day]
PAN1CL22T	17		40	6	0.0
PAN1CL32T	18		40	6	0.0
Stereo Combinations					
PAN1_PAN1	101	2	40	6	195.7
PAN1_PAN1CL11	104		40	6	0.0
PAN1_PAN1CL21	105		40	6	0.0
PAN1_PAN1CL31	106		40	6	0.0
PAN1_PAN1CL12	107		40	6	0.0
PAN1_PAN1CL22	108		40	6	0.0
PAN1_PAN1CL32	109		40	6	0.0
PAN1T_PAN1T	110		40	6	0.0
PAN1T_PAN1CL11T	111		40	6	0.0
PAN1T_PAN1CL21T	112		40	6	0.0
PAN1T_PAN1CL31T	113	2	40	6	367.0
PAN1T_PAN1CL12T	114		40	6	0.0
PAN1T_PAN1CL22T	115		40	6	0.0
PAN1T_PAN1CL32T	116		40	6	0.0
PAN1CL11_PAN1CL11	121		40	6	0.0
PAN1CL11_PAN1CL21	122	4	40	6	978.7
PAN1CL11_PAN1CL31	123		40	6	0.0
PAN1CL11_PAN1CL12	124		40	6	0.0
PAN1CL11_PAN1CL22	125	1	40	6	171.3
PAN1CL11_PAN1CL32	126		40	6	0.0
PAN1CL12_PAN1CL12	127		40	6	0.0
PAN1CL12_PAN1CL22	128		40	6	0.0
PAN1CL12_PAN1CL32	129		40	6	0.0
	Total data volume per day [Mbit/day]				2887.1

8.4.3 Low

It is assumed that, 1450 Mbit/day has been allocated to CaSSIS. An indicative distribution for one day is indicated. Trimming of the number of frames could be performed to meet the exact data volume available.

Acronym	ID	No. of images per day	Number of frames	Compression ratio	Data volume [Mbit/day]
Basic Structures					
PAN1	1		40	6	0.0
CL21	2		40	6	0.0
CL31	3		40	6	0.0

Acronym	ID	No. of images per day	Number of frames	Compression ratio	Data volume [Mbit/day]
PAN1CL11	4		40	6	0.0
PAN1CL21	5		40	6	0.0
PAN1CL31	6		40	6	0.0
PAN1CL12	7		40	6	0.0
PAN1CL22	8	2	40	6	146.8
PAN1CL32	9		40	6	0.0
Reduced Structures					
PAN1T	10		40	6	0.0
CL21T	11		40	6	0.0
CL31T	12		40	6	0.0
PAN1CL11T	13		40	6	0.0
PAN1CL21T	14		40	6	0.0
PAN1CL31T	15		40	6	0.0
PAN1CL12T	16		40	6	0.0
PAN1CL22T	17	2	40	6	110.1
PAN1CL32T	18		40	6	0.0
Stereo Combinations					
PAN1_PAN1	101		40	6	0.0
PAN1_PAN1CL11	104		40	6	0.0
PAN1_PAN1CL21	105		40	6	0.0
PAN1_PAN1CL31	106		40	6	0.0
PAN1_PAN1CL12	107		40	6	0.0
PAN1_PAN1CL22	108		40	6	0.0
PAN1_PAN1CL32	109		40	6	0.0
PAN1T_PAN1T	110	4	40	6	293.6
PAN1T_PAN1CL11T	111		40	6	0.0
PAN1T_PAN1CL21T	112		40	6	0.0
PAN1T_PAN1CL31T	113	2	40	6	367.0
PAN1T_PAN1CL12T	114		40	6	0.0
PAN1T_PAN1CL22T	115		40	6	0.0
PAN1T_PAN1CL32T	116		40	6	0.0
PAN1CL11_PAN1CL11	121		40	6	0.0
PAN1CL11_PAN1CL21	122	2	40	6	489.3
PAN1CL11_PAN1CL31	123		40	6	0.0
PAN1CL11_PAN1CL12	124		40	6	0.0
PAN1CL11_PAN1CL22	125		40	6	0.0
PAN1CL11_PAN1CL32	126		40	6	0.0
PAN1CL12_PAN1CL12	127		40	6	0.0
PAN1CL12_PAN1CL22	128		40	6	0.0
PAN1CL12_PAN1CL32	129		40	6	0.0
	Total data volume per day [Mbit/day]				1406.8

8.4.4 High

It is assumed that 5800 Mbit/day has been allocated to CaSSIS for this period. An indicative distribution for one day is indicated. Trimming of the number of frames could be performed to meet the exact data volume available.

Acronym	ID	No. of images per day	Number of frames	Compression ratio	Data volume [Mbit/day]
Basic Structures					
PAN1	1		40	6	0.0
CL21	2		40	6	0.0
CL31	3		40	6	0.0
PAN1CL11	4		40	6	0.0
PAN1CL21	5		40	6	0.0
PAN1CL31	6		40	6	0.0
PAN1CL12	7		40	6	0.0
PAN1CL22	8	8	60	6	880.8
PAN1CL32	9		40	6	0.0
Reduced Structures					
PAN1T	10		40	6	0.0
CL21T	11		40	6	0.0
CL31T	12		40	6	0.0
PAN1CL11T	13		40	6	0.0
PAN1CL21T	14		40	6	0.0
PAN1CL31T	15		40	6	0.0
PAN1CL12T	16		40	6	0.0
PAN1CL22T	17		40	6	0.0
PAN1CL32T	18		40	6	0.0
Stereo Combinations					
PAN1_PAN1	101		40	6	0.0
PAN1_PAN1CL11	104		40	6	0.0
PAN1_PAN1CL21	105		40	6	0.0
PAN1_PAN1CL31	106		40	6	0.0
PAN1_PAN1CL12	107		40	6	0.0
PAN1_PAN1CL22	108	3	60	6	550.5
PAN1_PAN1CL32	109		40	6	0.0
PAN1T_PAN1T	110		40	6	0.0
PAN1T_PAN1CL11T	111		40	6	0.0
PAN1T_PAN1CL21T	112		40	6	0.0
PAN1T_PAN1CL31T	113		40	6	0.0
PAN1T_PAN1CL12T	114		40	6	0.0

Acronym	ID	No. of images per day	Number of frames	Compression ratio	Data volume [Mbit/day]
PAN1T_PAN1CL22T	115		40	6	0.0
PAN1T_PAN1CL32T	116		40	6	0.0
PAN1CL11_PAN1CL11	121		40	6	0.0
PAN1CL11_PAN1CL21	122	8	60	4	4404.0
PAN1CL11_PAN1CL31	123		40	6	0.0
PAN1CL11_PAN1CL12	124		40	6	0.0
PAN1CL11_PAN1CL22	125		40	6	0.0
PAN1CL11_PAN1CL32	126		40	6	0.0
PAN1CL12_PAN1CL12	127		40	6	0.0
PAN1CL12_PAN1CL22	128		40	6	0.0
PAN1CL12_PAN1CL32	129		40	6	0.0
	Total data volume per day [Mbit/day]				5835.3

8.5 Implied long term coverage

We determine the areal coverage of Mars under the assuption of 10% overlap between frames.

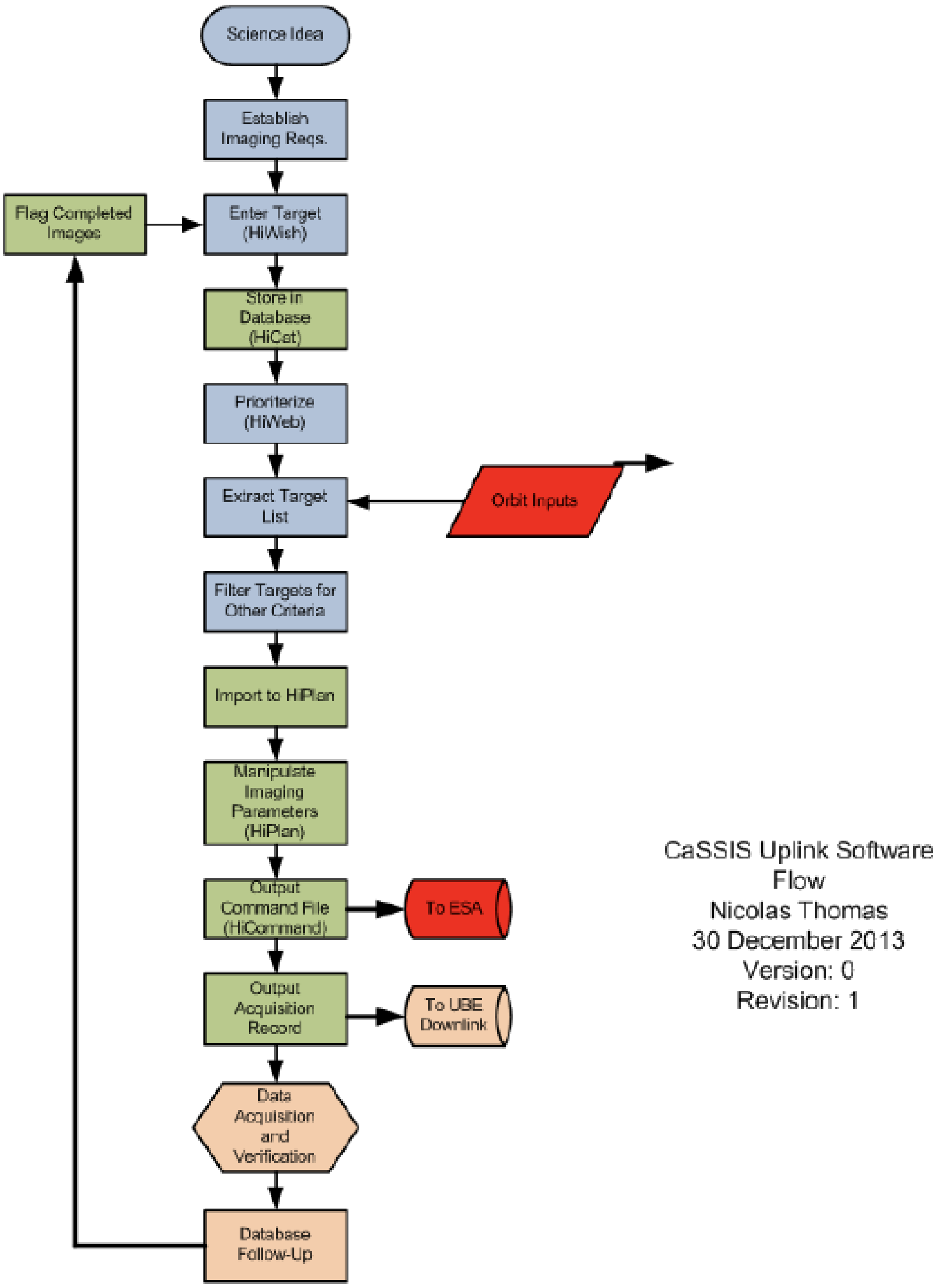
8.5.1 Average Case

	Total	Stereo	Colour
Areal Coverage [km2 per day]	8026.8	3498.9	7203.5
Areal Coverage [km2 per Mars year]	5514416	2403720	4948835
%age Areal Coverage [%Mars surface per Mars]	3.81%	1.66%	3.42%

This table shows we are compatible with our top level science requirements with the “average” plan.

8.6 Medium-Term Planning

To obtain the targets we follow the scheme indicated in the following figure.



The scheme takes advantage of the publicly accessible target proposal software (HiWISH) which will be adapted by University of Arizona to support CaSSIS.

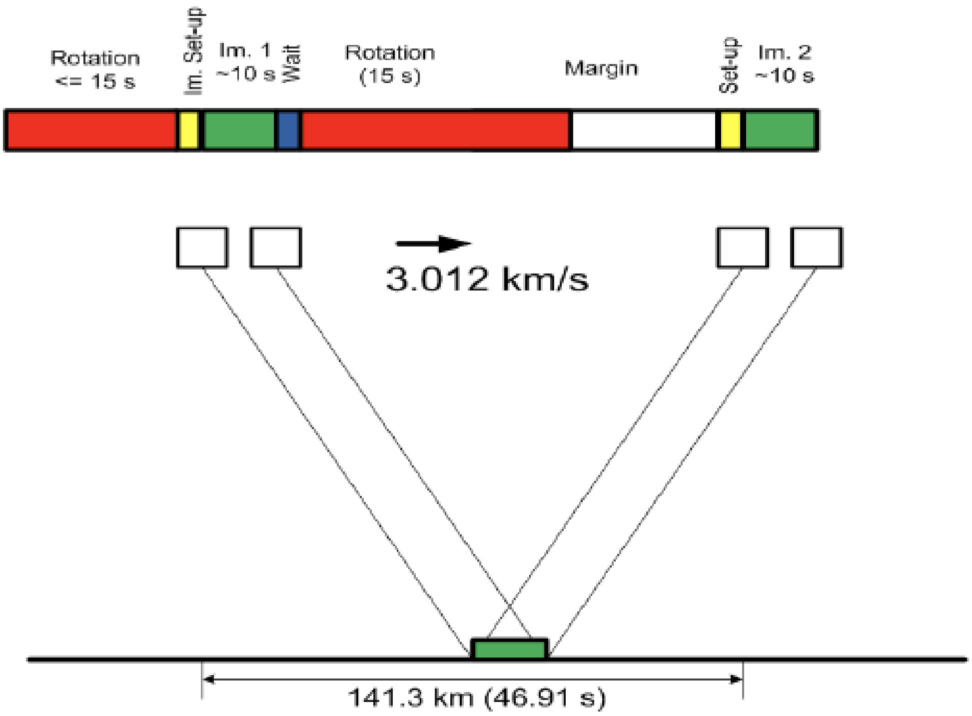
To support the generation of command files, ESA is requested to provide the format of the command file so that automated generation of commands can be programmed into the CaSSIS equivalent of the HiCOMMAND tool.

8.7 Short-Term Planning

[CAS-EOP-0050] The spacecraft is requested to provide low angle roll manoeuvres to compensate for orbit error to allow efficient collection of data for targetted observations.
Verification: R
Level: System
Info: Current error estimates on the orbit suggest that (for example) observations of landing sites cannot be accurately targetted without using a spacecraft role. This breaches a CaSSIS level 1 science requirement.

8.8 CaSSIS Operations Scheduling

The short term planning of CaSSIS operations will be finalised with precise timing information for the tele commands (TCs) entered into the Mission Time Line (MTL). This will depend on a number of factors associated with the TGO navigation. This process to fine tune the scheduling of CaSSIS operations will be more fully developed in the CaSSIS Flight Operations User Manual (FOUMA, RD03) and discussed in conjunction with the MOC and SOC. The following diagram provides an estimate for the precision of timing in seconds needed for a stereoscopic image capture.



9 In Flight Calibration

CaSSIS may want to perform in flight calibrations. It is assumed that these measurements will not be mission drivers. The calibration modes are:

9.1 Dark current

Observations of the nightside of Mars would be useful to assess the changes in the dark current on the detector. This can be performed once a month. A standard (typical) imaging sequence is to be performed (without rotation) to establish the dark current.

9.2 Straylight Calibration

An illuminated limb observation of Mars would provide the best assessment of straylight close to the boresight. Mars would cover around ¼ of the detector. The image field would be scanned through the field of view with repeated imaging. Ideally a second data set with Mars on the other side of the boresight would also be performed.

The following procedure should be followed.

Table 10: Requirements for straylight calibration

Requirement	Description	Comment
	Power on, health check, CaSSIS in SAFE MODE, download of HK data	
	Check of CONFIG mode, download of HK data	Modify selected parameters, repeat for characteristic parameter sets
	Check of LOW POWER STANDBY mode, download of HK data	
	HEAT UP and switch to STANDBY, download of HK data	
	Check MOTOR HOMING, download of HK data	
	It is desirable that spacecraft is fixed pointed so that the CaSSIS boresight (with the CaSSIS rotation mechanism in its default position) is roughly 1 deg off the illuminated limb of Mars.	
	Check IMAGE mode (single), download of HK data, download science data	Verify limb is on detector if pointing request has been accepted

Requirement	Description	Comment
	5 images in all filters shall be acquired. download of HK data, download science data	
	Check of data transmission to Earth	Transmission of all data generated in checks mentioned above

An alternative approach not requiring a slew to the limb would be to use the terminator crossings to provide upper limits for the straylight. The imaging approach in this case would be identical to a standard image. The target would be set to a position on the terminator and a standard imaging sequence acquired.

9.3 Absolute fluxes

Absolute calibrations should be performed in cruise. The spacecraft needs to point at relative bright sources like Jupiter or bright stars. The spacecraft needs to slowly slew across the desired targets. The desired slew rate is 1 degree per minute with a pointing accuracy of <0.1 degree. As the above mentioned sources do not cover the full detector, repeated imaging is performed to provide cross-detector variations in sensitivity. Figure 5 illustrates the procedure. The resulting images will be compared on ground to previous calibration results. CaSSIS estimates the procedure to last approximately 30 minutes.

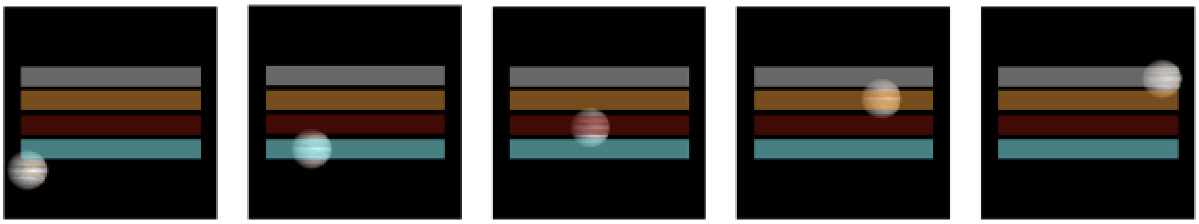


Figure 5: Illustration for in-flight calibration of absolute fluxes. Only five exposures are shown, the source (here: Jupiter) moves across the detector as the s/c slews.

A preliminary list of stellar calibration standards is given in the following table. Note that planetary targets (e.g. Jupiter and Saturn) can also be used for absolute flux calculations.

Table 11 Preliminary list of stars and starfield for CaSSIS calibration

Target	Stellar (S) or Geometric (G)	RA (J2000)	Dec (J2000)	HR	V (mag)	Spec. Type	Reference
73 Cet	S	02 28 09.4	+08 27 36	718	4.28	B9III	Hamuy

Target	Stellar (S) or Geometric (G)	RA (J2000)	Dec (J2000)	HR	V (mag)	Spec. Type	Reference
2 Ori	S	04 50 36.8	+08 54 02	1544	4.37	A1Vn	Hamuy
Area 98	G	06 52 05	-00 18 19		9.54		Landolt
Theta Crt	S	11 36 41.1	-09 48 08	4468	4.69	B9.5Vn	Hamuy
Area 104	G	12 43 07	-00 32 21		9.70		Landolt
Beta Cru	S	12 47 31	-59 40 11	4853	1.25		Breger
108 Vir	S	13 09 57.1	-05 32 18	4963	4.38	A1IVs	Hamuy
Vega	S	18 36 56.3	+38 47 01	7001	0.03	A0V	Hamuy/HST
58 Aql	S	19 54 44.7	+00 16 26	7596	5.61	A0III	Hamuy
Area 113	G	21 41 28	+00 40 14		10.00		Landolt
29 Psc	S	00 01 49.4	-03 01 39	9087	5.1	B7III-IV	Hamuy
Jupiter	S	Variable			-2	Solar	Thomas
Saturn	S	Variable			3	Solar	Thomas

This table can be significantly extended to meet constraints from the spacecraft (solar aspect angles etc. etc.) during cruise.

It is desirable but not a requirement that stellar calibration be repeated once TGO is in its science orbit.

The following procedure should be followed.

Table 12: Requirements for stellar calibration

Requirement	Description	Comment
	Power on, health check, CaSSIS in SAFE MODE, download of HK data	
	Check of CONFIG mode, download of HK data	Modify selected parameters, repeat for characteristic parameter sets
	Check of LOW POWER STANDBY mode, download of HK data	
	HEAT UP and switch to STANDBY, download of HK data	

Requirement	Description	Comment
	Check MOTOR HOMING, download of HK data	
	It is desirable that spacecraft is fixed pointed so that the CaSSIS boresight (with the CaSSIS rotation mechanism in its default position) is pointed at a CaSSIS in-flight stellar calibration target (see EXM-CA-TNO-UBE-00003).	The execution of this pointing request can be made at any time prior to this point.
	Check IMAGE mode (single), download of HK data, download science data	Verify star on detector if pointing request has been accepted
	5 images in all filters shall be acquired. download of HK data, download science data	
	The spacecraft shall slew in 0.2 deg steps and the previous step shall be repeated. This action shall take place 5 times per star/starfield.	
	Check of data transmission to Earth	Transmission of all data generated in checks mentioned above
	Check of data processing on Earth	Test entire data line from Ground Station to systematic processing of science data and distribution of results

9.4 Boresight measurement

Knowledge of our line-of-sight with respect to the TGO attitude control coordinate system can be performed in cruise. The spacecraft should point to known bright target and hold its pointing. Repeated images with CaSSIS will be used to determine the centroid of the target and thereby confirm the orientation of the boresight with respect to the star tracker determination. Two orientations of the spacecraft would be ideal.

The procedure would follow the same procedure as for stellar calibration.

9.5 Geometric calibration

A starfield is needed for this kind of calibration and should be performed in cruise. A slow slew across a known starfield will be performed. Several exposures are taken to cover the full detector.

An illustration is shown in Figure 6.

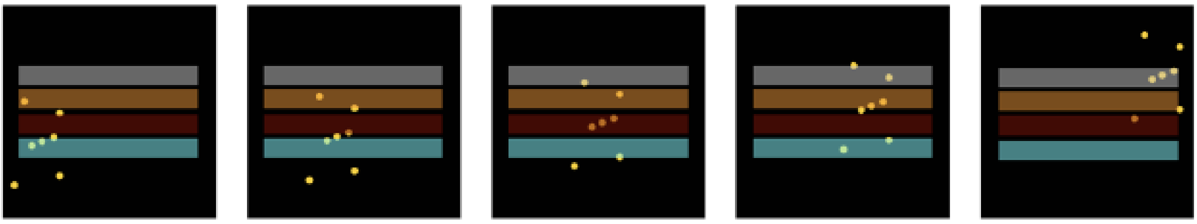


Figure 6: Illustration of in flight calibration of geometric distortion. The star field moves across the detector as the spacecraft slews. Several exposures (5 shown here) are taken.

Table 13: Requirements for geometric calibration

Requirement	Description	Comment
	Power on, health check, CaSSIS in SAFE MODE, download of HK data	
	Check of CONFIG mode, download of HK data	Modify selected parameters, repeat for characteristic parameter sets
	Check of LOW POWER STANDBY mode, download of HK data	
	HEAT UP and switch to STANDBY, download of HK data	
	Check MOTOR HOMING, download of HK data	
	It is desirable that spacecraft is fixed pointed so that the CaSSIS boresight (with the CaSSIS rotation mechanism in its default position) is pointed at a CaSSIS in-flight geometric calibration target (see EXM-CA-TNO-UBE-00003).	The execution of this pointing request can be made at any time prior to this point.
	Check IMAGE mode (single), download of HK data, download science data	Verify starfied on detector if pointing request has been accepted
	5 images in all filters shall be acquired. download of HK data, download science data	
	The spacecraft shall slew in 0.2 deg steps and the previous step shall be repeated. This action shall take place 5 times per star/starfield.	
	Check of data transmission to Earth	Transmission of all data generated in checks mentioned above
	Check of data processing on Earth	Test entire data line from

Requirement	Description	Comment
		Ground Station to systematic processing of science data and distribution of results

Details on the respective calibration modes and procedures can be found in RD02.

[CAS-EOP-0040] Calibration target observations shall be performed on average every 6 months during the mission.
Verification: R
Level: System

10 Operational Constraints

10.1 Sun-pointing

CaSSIS is compliant with the E-IRD. However, the following flight rules should be applied.

[CAS-EOP-0010] The boresight of CaSSIS shall be kept a minimum of 40 deg from the Sun at all times (excluding safe modes etc. as defined in the E-IRD).
Verification: R
Level: System
Info: This requirement applies to nominal operation.

[CAS-EOP-0020] The boresight of CaSSIS shall be kept a minimum of 70 deg from the Sun during nominal imaging operations.
Verification: R
Level: System
Info: Imaging in the range 40-70 deg elongation might be acceptible for straylight or special (non-nominal) imaging.

10.2 Rotation drive conflicts

[CAS-EOP-0030] In nominal operations, rotation of the telescope shall not occur during imaging. It shall be possible to override this via ground intervention for specific non-nominal operations/calibrations.
Verification: R
Level: System

11 Instrument Monitoring

11.1 Spacecraft operations monitoring

The following housekeeping parameters shall be monitored and the values herein used to generate alarms.

Parameter	Minimum	Maximum
Telescope temperature	-35 C	+65 C
ELU temperature	-45 C	+80 C

11.2 UBE daily monitoring

The following parameters shall be monitored via regular inspection of the downlink. The list is an example, the final list of Hk data will be agreed with MOC.

Parameter	Minimum	Maximum
Telescope temperature (M1)	-35 C	+65 C
Telescope temperature (M2)	-35 C	+65 C
ELU temperature 1	-45 C	+80 C
ELU temperature 2	-45 C	+80 C
Focal plane temperature	-5 C	-5 C
RCM board temperature	-40 C	+80 C
PE Temperature	-20 C	+24 C
Various voltages		
Memory consumption		
Rotation mechanism position		
Software status		
Conformation of sides being used (main/red)		
Timestamp		

12 Appendix A: Product Definitions

12.1 Overview

Data Set	Description	Producer	Publication
Raw telemetry	Data transmitted by spacecraft to ground	ESAC	No
Converted telemetry (Level 1)	TM converted and decompressed data in PDS V4.	ESAC (primary) UBE (secondary; verification)	Yes
Radiometric calibration (Level 2)	Individual sub-exposures calibrated and headers updated with preliminary geometry information in PDS V4	UBE	No
Standard product (Level 3)	Image swaths in individual colours, geometrically corrected, registered, correlated and stitched in PDS V4	UBE	Yes
Other products (Level 4)	Colour composite data Stereo reconstruction data Intention is to provide some data to PDS/PSA in PDS V4 format but this cannot be promised.	Many	Possibly

12.2 Calibration data

- Description
    - Raw image data
    - Housekeeping data
    - PDS V4 format
    - Produced at UBE
- Features
    - Data acquired at UBE during PFM testing
    - Currently undecided whether raw cal. data or derived products from cal. data will be provided.
- Availability
    - After clean-up by UBE

- Application:
    - Analysis of HK data during test
    - Validation of instrument commanding
    - Determination of instrument calibration
    - Determination of instrument performance
    - Data will be used to generate Level 2

12.3 Level 1 (Systematic data product)

- Description
    - Raw image data
    - Housekeeping data
    - PDS V4 format
    - Produced at ESA and UBE

- Features
    - Data decompressed

- Availability
    - Immediately after telemetry reception

- Application:
    - Analysis of HK data
    - Validation of instrument commanding
    - Validation of instrument health
    - Validation of data return
    - Data will be used to generate Level 2

12.4 Level 2 (Systematic intermediate data product)

- Description
    - Radiometrically calibrated data
    - Produced at UBE

- Features
    - The following corrections shall be made to the Level 1 data
        - Bias subtraction
        - Dark current subtraction
        - Flat-field subtraction
        - Conversion to absolute (physical) units
        - Insertion/update of headers to include spacecraft parameters
        - Insertion of preliminary geometry information (based on SPICE and/or navigation data as delivered by ESA)

- Availability

- After reception of spacecraft data

- Application
  - Preparation of data for geometric distortion correction and registration to generate Level 3

12.5 Level 3 (Standard data product)

- Description
  - Individual images, corrected for geometric distortion, registered, and stitched to produce image swaths in individual colours. Data in PDS V4.

- Features
  - Navigation data as delivered by ESA/ESTEC included.
  - Produced at UBE under the responsibility of the CaSSIS data processing team

- Availability
  - Fully available to the science community after validation.

- Application
  - Data will be used to generate Level 4 products

12.6 Level 4 (Scientific data products)

[Products requiring additional data from other ExoMars instruments, or a considerable amount of interpretation]

- Description
  - miscellaneous science results;
  - selection
    - DTM models
    - Colour images

- Application
  - Final data products

- Availability
  - 3 months after product completion.

13 Archive Flow

The basic flow to the archive will follow the following flow.