CASSIS EXPERIMENT TO ARCHIVE INTERFACE CONTROL DOCUMENT

Doc.No: EXM-CA-ICD-UBE-00003

Issue: 0

Revision: 13

Date: 4/23/2020

Instrument name:	Colour and Stereo Surface Imaging System (CaSSIS)
Origin Name:	Physikalisches Institut, Universität Bern
WBS code:	N/A
Package code:	N/A
Restrictions:	N/A

	Name	Signature	Date
Prepared by	Matthew Read Downlink Engineer		03 | 04 | 2020
Reviewed by	Nick Thomas Principal Investigator		23 | 12 | 2018
Approved by			
Authorised by	Leo Metcalfe (ExoMars 2016 SOC Development Manager)		

Document Change Record

Issue	Revision	Date	Pages, Tables, Figures affected	Modification	Initials
0	1	19 01 2016	All	New document	NT
0	2	14 01 2018		First full revision post-launch	NT
0	3	12 12 2018		Revisions of data levels and labels	MR/NT
0	4	27 06 2019	All	Pre-data review board revisions	MR
0	5	25 07 2019	All	Pre-data review board revisions	MR
0	6	05 09 2019	Tables 4 – 10	Addition of Tables defining contents of HK packets	MR
0	7	10 09 2019	Sec. 5.7	Addition of two wavelength related entries in level1c xml header example	MR
0	8	09 12 2019	Sec. 2.4.9, 4.2.2, 6.2.5, 6.4	Additional description of calibration files	MR
0	9	27 03 2020	All	Restructuring of EAICD following review	MR
0	11	07 04 2020	All	Addition of all types of labels and minor edits	MR
0	12	16 04 2020	Sec. 7, 8	Minor edits following review panel discussion	MR
0	13	23 04 2020	Sec. 3	Minor wording edits to update text tense	MR

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Reference documents

Applicable documents		
AD00	EXM-PL-IRD-ESA-00003 Issue 3 Rev 0 TGO E-IRD (JCCB - Signed)	Experiment Interface Requirements Document
AD01	EM16-SGS-PL-002	ExoMars 2016 Science Data Generation, Validation and Archiving Plan
AD02	EM16-SGS-TN-001	ExoMars 2016 Archiving Guide
AD03	PDS4 Standards Reference (SR)	
AD04	PDS4 Data Dictionary (DDDB)	
AD05	PDS4 Information Model Specification (IM)	

Reference documents		
RD01	EXM-CA-LIS-UBE-00001	List of Acronyms Iss 1 Rev 3
RD02	PDS4 Data Providers Handbook (DPH)	
RD03	PDS4 Concepts	
RD04	ExoMars 2016 SGS Acronyms	
RD05	EXM-CA-RSD-UBE-00003	System Requirements Document Iss 1, Rev 5
RD06	EXM-CA-PLN-UBE-00024	Experiment Operations Plan Iss 1, Rev 2
RD07	EXM-CA-PLN-UBE-10000	CaSSIS Calibration Programme Iss 1, Rev 1
RD08	TBC	CaSSIS Calibration Report
RD09	EXM-CA-PLN-UBE-10002	CaSSIS Data Archive Plan Iss 1, Rev 0
RD10	EXM-CA-RSD-UBE-10000	CaSSIS Science Requirements Document Iss 1, Rev 7
RD11	EXM-CA-PLN-UBE-00025	CaSSIS Science Implementation Plan Iss 1, Rev 1
RD12	EXM-CA-PLN-UBE-00017	CaSSIS Configuration Management Plan Iss 1, Rev 0
RD13	EXM-CA-UMA-UBE-00001	CaSSIS User Manual Iss 2, Rev 1

Reference documents		
RD14	EXM-CA-UMA-UBE-10001	CaSSIS Flight Operations User Manual Iss 0, Rev 4
RD15	Thomas et al. (2017)	Space Science Reviews Space Sci Rev (2017) 212:1897–1944 DOI 10.1007/s11214-017-0421-1

Purpose and Scope of Document

This Experiment-to-Archive Interface Control Document (EAICD) describes the format and content of the CaSSIS (Colour and Stereo Surface Imaging System) archived data in the Planetary Science Archive (PSA). It includes descriptions of the data products and associated metadata, including the data format, content, and generation pipeline.

The specifications described in this EAICD apply to all CaSSIS products submitted for archive to ESA's ExoMars 2016 Science Ground Segment (SGS), for all phases of the ExoMars 2016 mission.

Intended Readership

This document is intended for any user of CaSSIS data and the archiving team at the PSA. The primary focus of this document is to describe data as available from the PSA.

Archiving Authority

Planetary Science Archive

The Planetary Science Archive (PSA) is ESA's central repository for all products generated by ESA's solar system missions. The PSA allows for cross mission queries of data, where all data is stored in a common format, with a web client allowing for ease of data retrieval. The data format on the PSA adheres to the Planetary Data System (PDS) standard, with the latest version of the PDS standard being PDS version 4 (PDS4).

1 List of Acronyms

Term	Definition
CaSSIS	Colour and Stereo Surface Imaging System
CaST	CaSSIS Suggestion Targeting
CMOS	Complementary Metal Oxide Semiconductor
CRU	Camera Rotation Unit
DLR	German Aerospace Centre
DN	Detector counts
EAICD	Experiment to Archive Interface Control Document
EDM	Engineering Descent Module
ELU	Electronics Unit
EPFL	Swiss Federal Institute of Technology Lausanne
ESAC	European Space Astronomy Centre
ESOC	European Space Operations Centre
FPA	Focal Plane Assembly
FPGA	Field-Programmable Gate Array
FSA	Filter Strip Assembly
FSW	Flight Software
HiRISE	High Resolution Imaging Science Experiment
HiSCI	High-resolution Stereo Colour Imager
HK	Housekeeping
I/F	Reflectance
JMARS	Java Mission-planning and Analysis for Remote Sensing
MB	Megabyte
MRAM	Magnetoresistive random-access memory
MRO	Mars Reconnaissance Orbiter
MTP	Medium Term Plan
OPAD	Osservatorio Astronomico di Padova

Term	Definition
PDS	Planetary Data System
PE	Proximity electronics
PLAN-C	CaSSIS planning tool
PSA	Planetary Science Archive
SDRAM	Synchronous dynamic random-access memory
SGF	Space and Ground Facilities Ltd.
SGS	Science Ground Segment
STP	Short Term Plan
TBC	To be confirmed
TBD	To be determined
TC	Telecommands
TGO	Trace Gas Orbiter
TM	Telemetry
UBE	University of Bern
USGS	United States Geological Survey
UTC	Coordinated Universal Time

2 Mission Phases

Start Time	Acronym	Name
2016-03-14T00:00:00.000	necp	Near Earth Commissioning
2016-04-17T00:00:00.000	icp	Cruise
2016-10-16T00:00:00.000	mamp	Mars Approach and Orbit Insertion
2016-10-21T00:00:00.000	maop	Mars Arrival Orbit
2017-03-15T00:00:00.000	ap	Aerobraking
2018-03-09T00:00:00.000	cvp	Commissioning and Verification
2018-04-21T00:00:00.000	psp	Science Phase

3 CaSSIS Experiment General Description

A full description of the CaSSIS experiment, including scientific objectives and technical specifications can be found in the archived document Thomas et al. (2017)/RD-13. For clarity however, these objectives and specifications are summarized here.

3.1 Mission and Instrument Overview

The ESA ExoMars program consists of two stages: an orbiter (called Trace Gas Orbiter, TGO) launched in 2016 and a rover to be launched in 2022. 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 carries a camera called CaSSIS (Colour and Stereo Surface Imaging System) developed by the University of Bern (UBE), which takes high resolution stereo images in 4 colours of the Martian surface. Figure 1 illustrates the imaging concept. This imager characterizes sites which have been identified as potential sources of trace gases, investigates dynamic surface processes and certifies future landing sites. CaSSIS observes a 9 km wide swath thereby providing the best colour imaging acquired from Mars, so far.

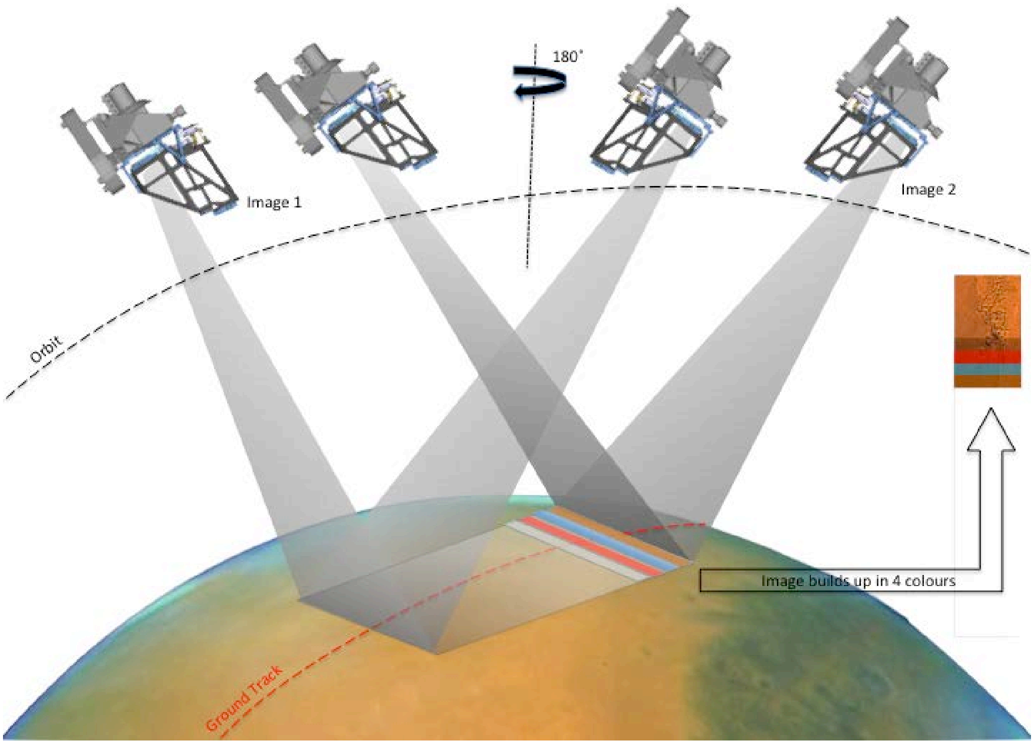

Figure 1: CaSSIS Stereo Image Acquisition

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

3.2 Scientific Objectives

The scientific objectives are summarized in the CaSSIS Science Requirements Document [EXM-CA-RSD-UBE-10000] and the System Requirements Document [EXM-CA-RSD-UBE-00003]. This document is the formal starting point from which other CaSSIS requirements have been derived and laid down, i.e., the telescope requirements or software requirements. The top level science requirements are repeated below.

Image and analyze surface features possibly related to trace gas sources and sinks in order to better understand the broad range of processes that might be related to trace gases.
The science team have, and continue to, compile and prioritize a list of observation targets needed to test specific hypotheses concerning active surface processes on Mars. This objective began to be addressed early in the mission, prior to current and future trace-gas discoveries from the TGO. CaSSIS supports such discoveries, as unusual or changing colors indicate active processes, perhaps linked to methane formation or release.

Map regions of trace gas origination as determined by other experiments to test hypotheses.
The TGO experiments are designed to discover trace gases and study atmospheric dynamics to trace the gases back to their source regions (perhaps to tens of km). CaSSIS places top priority on imaging these regions to formulate and test specific hypotheses for the origin and/or release of trace gases.

Search for and help certify the safety of landing sites driven by the TGO discoveries.
The discovery of methane has helped stimulate exploration plans in Europe and the U.S. A portion of NE Syrtis Major was approved for the landing site of the Mars Science Laboratory (largely from Mars Reconnaissance Orbiter (MRO) coverage); this site is at the margin of the Syrtis Major methane plume identified by Mumma et al. (2009). The landing sites for the NASA and ESA rovers to be launched in 2020 and 2022 respectively, also consider methane areas. These locations have been, and continue to be, imaged by TGO and MRO/High Resolution Imaging Science Experiment (HiRISE). CaSSIS cannot identify meter-scale hazards for these sites, but can provide the 5 m scale slope information in stereo to support HiRISE observations.

3.3 Experiment Overview

Whilst the goals and objectives of TGO are rather straightforward, the spacecraft design proposed by ESA did present some difficulties for remote-sensing. The spacecraft is generally nadir-pointing but rotates about the nadir-pointing axis in order to maintain the solar panels orthogonal to the Sun while keeping the Sun away from spectrometer radiators. This is an issue for high resolution imaging systems. This motion can be stopped for short durations to allow imaging but the orientation of the detector lines should be orthogonal to the direction of motion over the surface, which varies however depending upon orbital position.

In order to obtain a stereo pair from one pass over an object the camera system needs to be tilted or rotated. The concept originally developed for the High-resolution Stereo Colour Imager (HiSCI, McEwen et al., 2011a) is an elegant solution to the dual problem of the rotation of the platform about the nadir vector plus the requirement for stereoscopic imaging. Here it is the instrument that moves and not the whole spacecraft and rotation accomplishes not only the stereoscopic objective but also the compensation for the spacecraft attitude. There is no obvious and simple alternative to this approach for imaging on TGO and hence it was necessary to use this approach for CaSSIS, too.

Often cameras on space missions adopt a push-broom acquisition mode: the detector is a linear array and the full bidimensional image is reconstructed by quickly scanning a one line of pixels and placing all lines side by side successively at a suitable rate determined by the spacecraft velocity. CaSSIS employs a quasi-push broom mode, also called push-frame. The detector is a hybrid Complementary Metal Oxide Semiconductor (CMOS) active pixel sensor bidimensional array, so actual 2D images (frames) of the planet surface are acquired. The frames are acquired with overlap to allow subsequent correlation, matching and stitching. Each of the two stereo image pairs are acquired at two different moments: the forward image is acquired from a defined area on the planet surface by pointing 10 degree ahead (off nadir), then the same area is acquired after some time (which depends on the orbit of the spacecraft but is in the order of 45 seconds) by rotating the telescope 180 degrees to point 10 degrees behind. The 10 degree look angle increases the pixel scale and atmospheric path length by only 1.5%, yet provides a slightly larger than 20 degree stereo convergence angle (accounting for planetary curvature). The proper yaw orientation imaging is not precisely parallel to the ground track because Mars rotates, and this offset also ensures excellent overlap between the 2 stereo images (maximum mismatch is 3% of the swath width near the equator).

3.4 Instrument Description

CaSSIS is based around an 875 mm focal length carbon-fibre reinforced polymer telescope with a 135 mm primary mirror and a 2048 x 2048 CMOS hybrid detector with 10 micron pixel pitch providing 4.6 m/px imaging from the nominal 400 km circular orbit. The telescope is a slightly modified three mirror anastigmat optical configuration with no central obscuration. The instrument is designed to operate in “push-frame” mode where 2048 x 256 images are acquired at a repetition rate which matches the ground-track velocity (~3 km/s) allowing sufficient overlap for co-registration thereby building image strips along the surface.

The full 2048x2048 pixel window is referred to as a window. The individual 2048x256 pixel images within the CaSSIS window are referred to as framelets (see Figure 2).

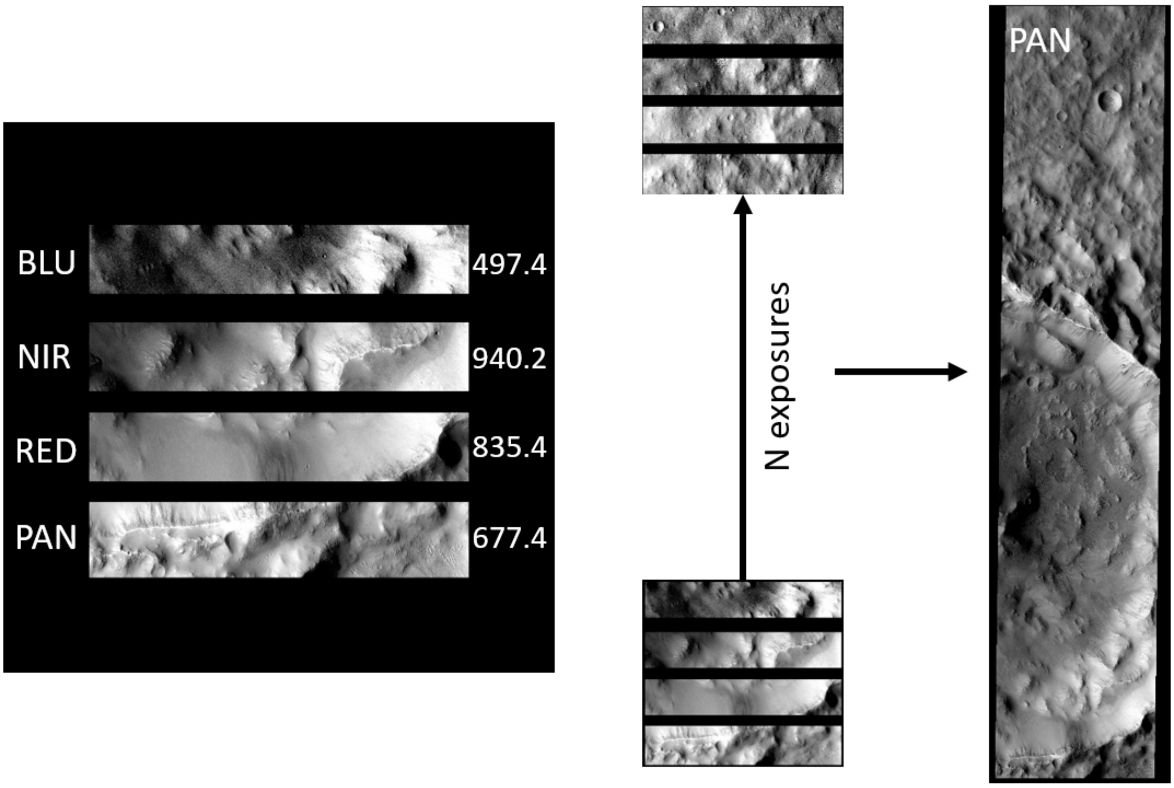

Figure 2: *(left)*: CaSSIS 2048x2048 pixel window with the four filters. Numerical values are the central wavelength of each filter in nm. A single CaSSIS exposure gives a sub-image in each of the chosen filters of 2048x256 pixels, referred to as a framelet. By taking N exposures, the framelets for each filter can be stitched together to make an image swath in that filter. *(right)*: The stitched image in PAN.

The instrument acquires colour data quasi-simultaneously. The push-frame detector is covered with the Filter Strip Assembly (FSA) which contains four filters composed of fused silica providing broad-band wavelength filtering. At each timestep, the four colours are read-out of the detector. Image acquisition/read-out is so fast that the following image can be acquired before all of the previously observed field is out of the field of the new frame. This allows overlap and for a continuous swath in each of the four colours. Figure 2 shows a single CaSSIS window with the four filters and how continuous image swaths are created. Figure 1 shows how this is combined with the stereo acquisition.

The FSA is mounted directly above the detector providing images in 4 wavelength bands. Two of these (497.4nm and 677.4nm) correspond closely to bands used by the HiRISE instrument on the Mars Reconnaissance Orbiter. Two other filters split the NIR wavelengths with centres at 835.4 nm and close to 940.2 nm. Analyses show that the filters provide good differentiation between expected surface minerals, particularly Fe-bearing phases. Either side of the 4 filters on the detector window are control windows which are used to periodically check the signal across the detector. Control window observations are not used for science observations.

CaSSIS is designed to produce stereo from images acquired ~45s apart by using the rotation drive. It should be clear that colour can be acquired on both stereo frames. This would usually provide redundant information and hence only panchromatic data is actually needed for one of the two stereo acquisitions.

The instrument has flexibility in image acquisition (swath width, swath length, binning, compression, etc.). The average total data volume was set at 2.9 Gbit/day. This would typically allow 4-6 stereo pairs plus several additional non-stereo targets per Mars day. CaSSIS internal processing constraints allowing for a maximum of 5 images to be taken per TGO orbit (assuming day side imaging and a TGO orbit of ~2hrs). However, typically 1-3 targets are acquired per orbit. Coverage will be of ~2% of the Martian surface per Mars year.

4 DATA GENERATION PROCESS

CaSSIS science products are produced by the CaSSIS Instrument Team and at the European Space Astronomy Centre (ESAC). The data generation process is summarized in Figure 3 with each step detailed below. All stages of the data generation process below are run by the CaSSIS team unless otherwise stated. The teams responsible for the creation/management of software for each stage of data generation are given below and by the acronyms beneath each data generation stage in Figure 3. This Section describes which data sets, out of those generated, are ingested into the PSA. Explanation of the naming conventions and format of ingested data on the PSA is given in Section 6.

4.1 Planning

4.1.1 CaST

Regions of interest for CaSSIS observations are selected by members of the CaSSIS science team via the CaSSIS Suggestion Targeting (CaST) web interface. Each region is selected in CaST with requested illumination conditions, image type (stereo/individual image), number of images required and region importance. These regions form a library of targets that can be queried for selection during the planning of CaSSIS commanding for a given time period. CaST was created and is maintained by the University of Arizona.

Currently only members of the CaSSIS science team can use CaST to add to the library of requested CaSSIS targets. However, CaST will be opened to the public at a TBD date.

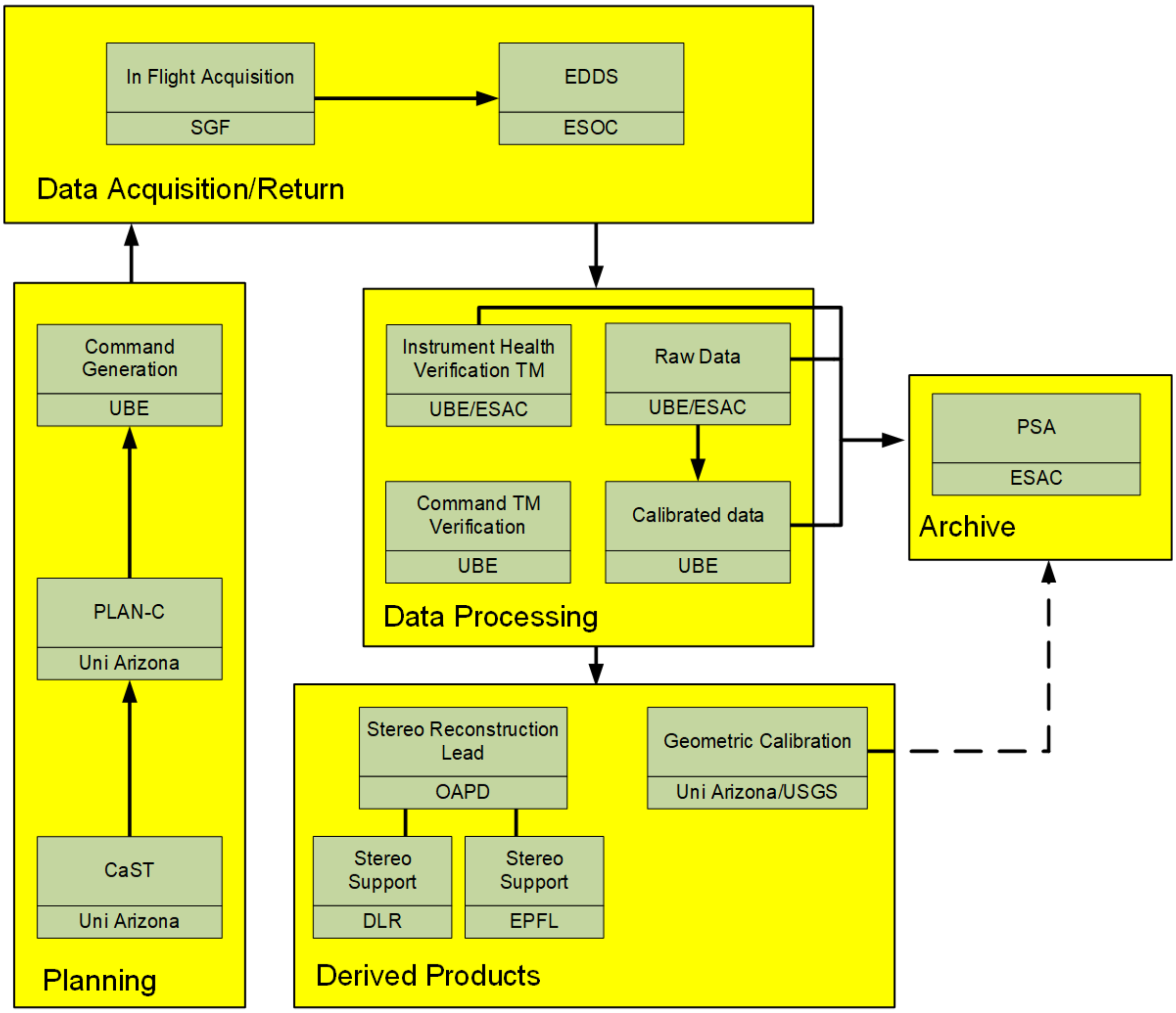

Figure 3: CaSSIS Data Generation Process. The acronyms below each generation step refer to the institution responsible for the associated software.

4.1.2 PLAN-C

Members of the CaSSIS science team take it in turns to plan what images will be acquired by CaSSIS in a given time period. Typically, a science team member plans two weeks of CaSSIS images during a given planning cycle.

Planning of images is done via the PLAN-C tool, which is used as a layer in JMARS. PLAN-C was created and is maintained by the University of Arizona. The predicted orbital track of TGO is loaded into this tool to see where CaSSIS can observe during a given TGO orbit. The library of targets from CaST is then also loaded into PLAN-C. The CaSSIS planner selects where CaSSIS acquires images, based on the targets suggested from CaST. For TGO orbits where no/not enough CaST targets are available for imaging, the planner can choose their own targets for observation. Typically, 1-3 images (subject to image specifications, downlink data volume and assuming day side observations) are acquired per TGO orbit.

Images are selected inside PLAN-C with the following parameters to fulfil CaST target requests and downlink data volume constraints:

- Which filters to use (PAN, RED, NIR, BLU).
- Width of framelet in each filter requested.
- Number of framelets.
- Compression (None, Lossless, Lossy).
- Binning configuration.
- Image type (stereo or individual image).

A pointing type of 'nadir' or 'targeted' is also assigned to each image. Images with nadir pointing are acquired when TGO is nadir pointing. Images with a targeted pointing are those where TGO is orientated such that CaSSIS can observe a specific target. Here, TGO can roll up to 5degrees off the nominal nadir ground track for CaSSIS observations. Due to the orbital constraints of TGO however, only 1 image with a targeted pointing can be acquired per TGO orbit.

For epochs of high downlink data volume, nadir images therefore make up the bulk of CaSSIS images. Targeted images are reserved for high importance targets that are outside the nominal nadir CaSSIS observing track.

Upon completion of target selection, PLAN-C exports a file containing information about each planned image, which is used for the generation of CaSSIS commands.

4.1.3 Command Generation

Details of images selected for imaging through the PLAN-C tool are ingested into a pipeline to turn this information into CaSSIS commands. This pipeline is written in IDL and was created/is maintained by UBE. The output from the pipeline are all the commands that will be executed by CaSSIS as part of the nominal Mission Timeline (MTL), including the imaging commands for the targets output from the PLAN-C tool. That is, the pipeline outputs *all* the commands needed for CaSSIS operation and not just the imaging commands.

For full details on CaSSIS commanding and operational modes refer to the Experiment Operations Plan (EXM-CA-PLN-UBE-00024), [RD05].

Specific information regarding image acquisition is encoded in the CaSSIS commanding via a parameter table. A typical parameter table results in an acquisition of an image with a footprint of 9.5 km x ~30 km for the total image, with each framelet typically being 9.5 km x 1.3 km. Each framelet produces a 1.05 MB image in raw form which will be expanded to a 4 byte integer on ground (i.e. 2.10 MB per framelet). Commanded onboard compression means that raw files may be factors of several smaller. Each image in one colour resulting from an exposure sequence is around 84 MB after expansion. A colour data set from one target can be up to 400 MB on disk. A stereo pair is typically 600 MB (assuming limited colour redundancy).

Commanding is sent to ESAC for verification before transmission to the spacecraft.

4.2 Data Acquisition/Return

4.2.1 In Flight Acquisition

Each target is acquired according to the MTL by the CaSSIS Flight Software (FSW). The flight software was produced and is maintained by Space and Ground Facilities Ltd. (SGF). For a typical image acquisition, image preparation commands are first executed, followed by image acquisition commands.

The image preparation commands include the setting of the parameter table. The parameter table sets the swath width, swath length, binning, compression and filters of the image to be acquired. The swath width is set by the number of pixels to be acquired cross-track. The swath length is controlled by the number of exposures in the exposure sequence.

The subsequent image acquisition command acquires an image according to the above parameters. Each exposure generates 1-4 framelets, depending on the number of filters used. Each framelet is written to memory in the form of a CaSSIS packet. Each CaSSIS packet contains both the header information regarding that framelet acquisition and the framelet image data. A typical raw CaSSIS image packet has a size of ~1.05MB.

For details of in-flight calibrations applied to the data (binning, compression etc.), Section 9 in the Experiment Operations Plan (EXM-CA-PLN-UBE-00024, [RD05]), can be referred to.

CaSSIS packets are sent to the main spacecraft for storage. Here, packets are grouped into ‘science files’ which have a unique identifier set in the commanding. A typical science file contains the CaSSIS image packets of two full image sequences.

Instrument diagnostic housekeeping (HK) telemetry (TM) and a record of executed CaSSIS commands are written as CaSSIS packets only and not grouped into science files. Diagnostic TM is typically sampled every 30 seconds.

4.2.2 EDDS

CaSSIS data is downlinked and made available through the European Space Operation Centre (ESOC) Electronic Data Dissemination System (EDDS). Science files, instrument TM and executed command logs for a specific epoch are queried by stored by the CaSSIS team at UBE.

Instrument HK TM is queried as a data file which contains a concatenation of all TM packets within the queried time range, where the contents of each TM packet is a hexadecimal string.

Executed telecommands are also queried as a data file, with the same format as TM data files. However, a human readable form of the executed telecommands is also queried for quick read analysis.

4.3 Data Processing

The PSA defines different data processing levels shown in Table 1. This document follows these definitions for describing data output at the different stages of processing.

Processing Level	Processing Level Acronym	Definition
Telemetry	tm	Original binary stream packets as produced by instrument or spacecraft subsystem.
Raw	raw	Unprocessed instrument count data extracted from telemetry packets. In those cases where on-board compression has been applied, raw products contain the decompressed version of the data.
Partially Processed	par	Raw products processed beyond the raw stage but which have not yet reached calibrated status.
Calibrated	cal	Raw or partially processed products converted to physical units where all of the calibration has been applied.
Derived	der	Results that have been generated from one or more calibrated products (for example: mosaics, maps, resampled data).

Table 1: Data level definitions used by the PSA.

4.3.1 Instrument Health Verification TM

Data from the data file containing the HK TM queried from the EDDS is extracted by an IDL pipeline, which was written and is maintained by UBE. CaSSIS HK TM describes different types of diagnostic information, including: temperatures, voltages, currents, motor rotation status and FSW status (see CaSSIS flight software manual, EXM-CA-UMA-UBE-10001, for an exhaustive list of all the parameters included in the HK TM. A summary of parameters is also given in Section 7.4).

Broadly speaking, HK TM can be separated into 7 different ‘types’: 1 – CaSSIS temperature, 2 – CaSSIS zone temperature, 3 – voltages and currents, 4 – proximity electronics HK and motor rotation status and 5, 6, 7 – FSW status.

The information extracted from HK TM packets by the IDL pipeline are output as IDL structure files, with specific HK information being graphically output for validation purposes (see Section 5 for further discussion of data validation).

ESAC also generates HK TM. Here the TM is stored according to one of the 7 HK TM types listed above (they are labelled using the hexid version of the integer type number however). A PDS4 compatible xml file is generated, containing data between two dates. This xml file is ingested into the PSA.

4.3.2 Command TM Verification

The data file queried from the EDDS containing the telecommands executed by CaSSIS is analysed by an IDL pipeline written and maintained by UBE. The data file is converted from a hexadecimal byte string into an IDL structure, containing all the commands executed during the time period of the data file. This structure file is also output as a report file for verification purposes. A separate IDL structure file is also generated with the parameters used for each command executed.

Checks of whether commands extracted are recognised are performed for verification as part of this IDL pipeline. Commanding information is not delivered to the PSA.

4.3.3 Raw Data

Raw science data is extracted from science files queried from the EDDS by an IDL pipeline created and maintained by UBE. The individual CaSSIS packets are first extracted from a given science file, where each packet contains the image data and header information for a single framelet. Image data from each packet is subsequently extracted and stored in a data file. The data files are 4-byte floating points in a 2D array, where the data is stored as an unformatted binary. De-compression of image data is performed during this step if required.

The header information from each packet is also extracted and stored as an xml file. This header information contains HK data pertaining to that acquisition and geometry information taken from SPICE kernels, amongst other general meta information.

A single piece of CaSSIS raw data is therefore the image data for a single framelet in a given filter with a corresponding xml header file.

The xml header files produced by the CaSSIS team are not PDS4 compatible. Instead, a parser has been written and is maintained by ESAC to convert the xml files produced by UBE to have labels that are PDS4 compatible.

ESAC also extracts raw data from science files in the same way as UBE and produces a PDS4 compatible xml file for each framelet data file. An example of a PDS4 compatible label for CaSSIS data is shown in Section 7.

Raw science products (framelet data file and corresponding XML header file) produced by UBE are supplied to ESAC. Upon delivery to ESAC the xml header files for each framelet are put through the parser by ESAC to convert them into being PDS4 compatible.

The raw framelet data files and corresponding PDS4 compatible xml headers produced by ESAC are ingested into the PSA (see Section 6 and 7 for filename and label conventions respectively). However, regular comparisons are made by ESAC between the xml header files delivered by UBE (once made PDS4 compatible by the parser) and the header files produced by ESAC to make sure they are consistent. If the CaSSIS team update the xml header file for raw data, ESAC regenerate all xml headers of raw data in the PSA to reflect this change. This regeneration is done roughly every 6 months if needed.

Browse products for raw data (individual framelets) are produced by ESAC and not by UBE. These browse products are ingested into the PSA with corresponding PDS4 compatible xml files (see Section 6 and 7 for filename and label conventions respectively).

4.3.4 Calibrated Data

Calibrated data is produced by an IDL pipeline created and maintained by UBE. The steps to convert raw data into calibrated data are performed in the following order:

- Bias calibration.
- Flat calibration.
- Bad pixel calibration.
- Expand binned data.
- Perform absolute calibration.
- Straylight calibration.
- Framelet to framelet offset correction.

A detailed description of the calibration steps can be found in the CaSSIS Calibration Report which is planned to be archived during 2020. An overview of the on-ground calibration can also be found in the CaSSIS Calibration Programme (EXM-CA-PLN-UBE-10000) [RD06] archive document. A summary of each part of the calibration procedure however, is given in this Section.

Calibrated data is stored as data files for each framelet with a corresponding xml header file. The data files are 4-byte floating points in a 2D array, where the data file is an unformatted binary. The xml header files for calibrated data produced by UBE are not PDS4 compatible. Similarly to the raw data, calibrated data is delivered to ESAC, where the xml files are put through a parser to make them PDS4 compatible. An example of a PDS4 label is shown in Section 7.

The calibrated framelet data files produced by UBE and corresponding PDS4 compatible xml header files are ingested into the PSA (see Section 6 and 7 for filename and label conventions respectively).

Browse products for individual calibrated framelets are not produced by UBE. Instead, calibrated framelets for a complete image acquisition, in a given filter, are stitched together by UBE using SPICE kernels to make a 'stitched browse' product. An example of a stitched browse product is shown by the right panel in Figure 2.

Note that herein the terms 'browse' and 'stitched_browse' products have distinct definitions. Specific browse products refer to a browse product of a single framelet in a single filter (like those produced for the raw framelet data). Stitched_browse products refer to the browse product of all framelets in a given filter from a given imaging sequence that are stitched together to give the entire image swath (like those produced for the calibrated data).

Stitched browse products are stored as JPG files with a corresponding non-PDS4 compatible xml header file. Stitched browse products and the corresponding header files are delivered to ESAC. The xml headers are made PDS4 compatible using the ESAC parser. Both the stitched browse product and PDS4 compatible xml file are then ingested into the PSA (see Section 6 and 7 for filename and label conventions respectively).

4.3.4.1 Bias Calibration

The CaSSIS bias frame is creating by UBE using in-flight exposures of the night side of Mars, with an exposure time similar to a typical nominal exposure (~1.5ms). The number of exposures to create the bias frame for each filter are: PAN – 330, RED – 240, NIR – 210, BLU – 390. Comparisons with a bias frame created with 150 exposures in each filter showed no significant variation. The current bias frame used by UBE in the calibration of raw data is therefore deemed to be stable with little/no future improvements expected. Bias frame subtraction is performed on the raw data following standard convention.

The bias frame used by UBE is archived in the PSA as a calibration product. It is stored as a data file as 4-byte floating points in a 2D unformatted binary array. The pixel dimensions of the bias are equal to the full CaSSIS detector window of 2048x2048 pixels. A corresponding xml file is delivered to ESAC, which is made PDS4 compatible after passing through the ESAC parser before being ingested into the PSA.

4.3.4.2 Flat Calibration

The CaSSIS flat frame is generated by UBE using in-flight day side Mars images only. Images are judged to be suitable for inclusion in the flat frame if they have a low standard deviation along the averaged x and y dimensions. Saturated images and those with lossy compression are rejected. The threshold for low standard deviation is judged empirically.

The current number of total images used in the flat frame is: PAN – 702, RED – 50, NIR – 47, BLU – 301. The total number of exposures used in the flat frame is: PAN: 21060, RED – 1500, NIR – 1410, BLU – 9030, assuming each image contains 30 exposures. Comparison with a flat containing significantly fewer images showed little variation. No significant future change is therefore expected with the current version of the flat frame. Flat frame calibration is performed on data following standard convention.

The flat frame used by UBE is archived in the PSA as a calibration product. It is stored as a data file as 4-byte floating points in a 2D unformatted binary array. The pixel dimensions of the flat are equal to the full CaSSIS detector window of 2048x2048 pixels. A corresponding xml file is delivered to ESAC, which is made PDS4 compatible after passing through the ESAC parser before being ingested into the PSA.

4.3.4.3 Bad Pixel Calibration

Image pixels from in-flight data, that have been visually identified by UBE to have zero/significantly weak signal, are calibrated out. Given that a full CaSSIS exposure has a dimension of 2048 x 2048 pixels, where the (0,0) pixel is the bottom left of the full exposure, the following pixels, (x,y), are calibrated out: (914, 1584), (1260, 440), (1435, 543), (1436, 542), (1436, 543), (1436, 544), (1437, 543), (1437, 544), (1438, 543), (1998, 587).

Pixels are calibrated out by interpolation using a nearest neighbor algorithm.

4.3.4.4 Expand Binned Data

Binned data is expanded following standard convention.

A bug exists in the current version of the CaSSIS FSW (v1.03 as of 01/04/2020) related to binning. Binned images can have sections of framelets that are shifted compared with where they are meant to be. A common example of this, is for a framelet to be separated roughly down the middle in the y direction (along track direction), with the left and right side of the framelet being switched with each other.

Routines have been created by UBE in the calibration pipeline to 'de-shift' the data in binned framelets. However, data reconstruction is not possible for certain binning configurations. Moreover, for some binning configurations rows of pixels are corrupted by the FSW and are not recoverable.
A fix for this issue in the FSW is expected at a future date. This issue is not significant for the vast majority of CaSSIS data however, as binning is seldom used for CaSSIS images (if binning is required to increase signal in a given image for example, it is assumed that this will be done in post processing).

Binned images also do not have a dedicated bias and flat frame. For these cases, the bias and flat is binned to the same configuration of the image before calibration.

4.3.4.5 Absolute Calibration

A conversion from detector counts (DN) to reflectance (I/F) is made with the following conversion:

$I/F = conversion * d_h^2 DN/t\_exp$,

where:

- d_h = heliocentric distance

- t_exp = exposure time
- conversion = conversion factor from on ground testing of detector, including detector gain, pixel size, transmission efficiency in given filter etc. The conversion factor for each filter is fixed at: [1.34e-8, 3.49e-8, 3.64e-8, 2.65e-8] s/m^2 for [PAN, RED, NIR, BLU] respectively. Specific details of the measurement of this calibration factor will be given in a future absolute calibration publication.

4.3.4.6 Straylight Calibration

During science phase operations it was found that exposures can be subject to straylight contamination. The contamination was traced to be from indirect sunlight reflecting off part of the detector sun-shield into the detector. The pattern of the straylight contamination was found to be extremely stable between different images, with only a changing intensity. The stability of the pattern is the topic of on-going analysis, but is assumed to be due to indirect sunlight only being reflected into the detector by the sun-shield for very specific orbital geometries. The pattern resembles a band like structure along the x direction of the detector. That is, for a given y pixel value on the detector, the straylight pattern does not vary in the x direction. An example of the straylight pattern is shown in the left panel of Figure 4. Typically, the mean contribution of straylight is less than 1% of the counts for a given pixel.

The straylight pattern has been modelled by UBE for subtraction off framelet exposures. The modelled pattern is a function of y pixel only (as there is no change in the pattern in the x pixel direction). For a given exposure, the straylight procedure is as follows:

- For a given y pixel value in a framelet, the x pixel values are averaged, so that the framelet has values in the y pixel direction only.
- The modelled straylight pattern is fit to this collapsed framelet (as the modelled straylight pattern changes in y only).
- The best fitting straylight pattern is subtracted from the corresponding y pixel values of the framelet.

This calibration technique is suitable for framelets with significant or zero straylight contamination as, for example, if a framelet has zero straylight, the best fitting model straylight pattern is one with zero amplitude.

An example of a full detector exposure after straylight calibration is shown in the right panel of Figure 4. The success of the straylight removal has been judged empirically by eye. A full statistical analysis of the straylight removal will be presented in the CaSSIS Calibration Report (to be archived in 2020), including the presence of residual straylight. However, as the typical mean contribution of the straylight is less than 1% of the total counts for a given pixel, the residual contribution can be expected to be far below this value. Whether to archive the straylight pattern in the PSA will be decided with the publication of this report.

4.3.4.7 Framelet to Framelet Offset Correction

Bulk brightness offsets between neighboring framelets have been seen to be present in images. An example is shown in the left panel of Figure 5. Here, framelets for a given filter have been stitched together to highlight this bulk offset between framelets.

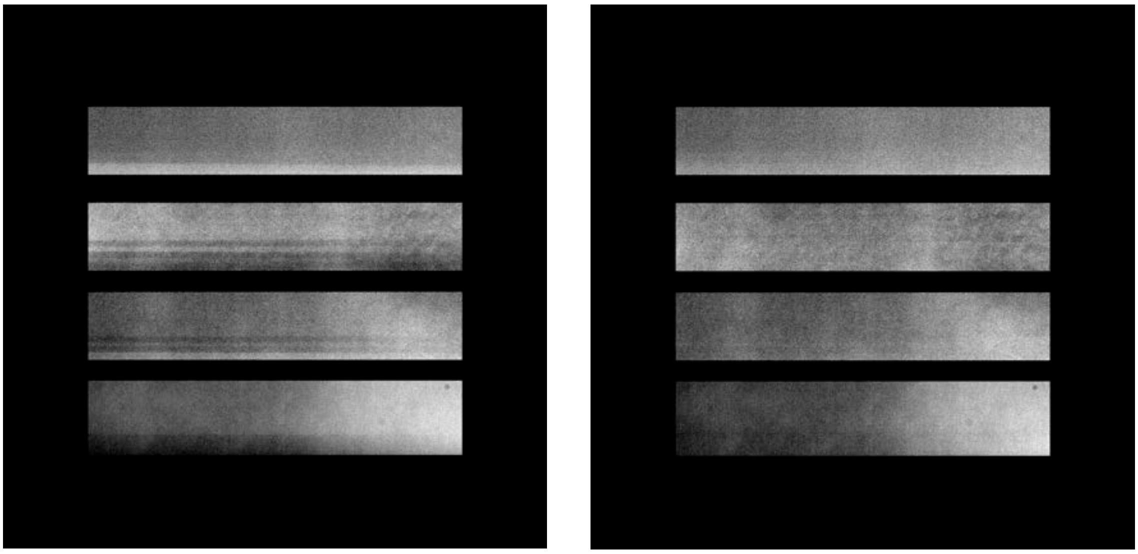

Figure 4: CaSSIS window exposure before straylight calibration (left) and after (right). Straylight manifests as horizontal bands across framelets.

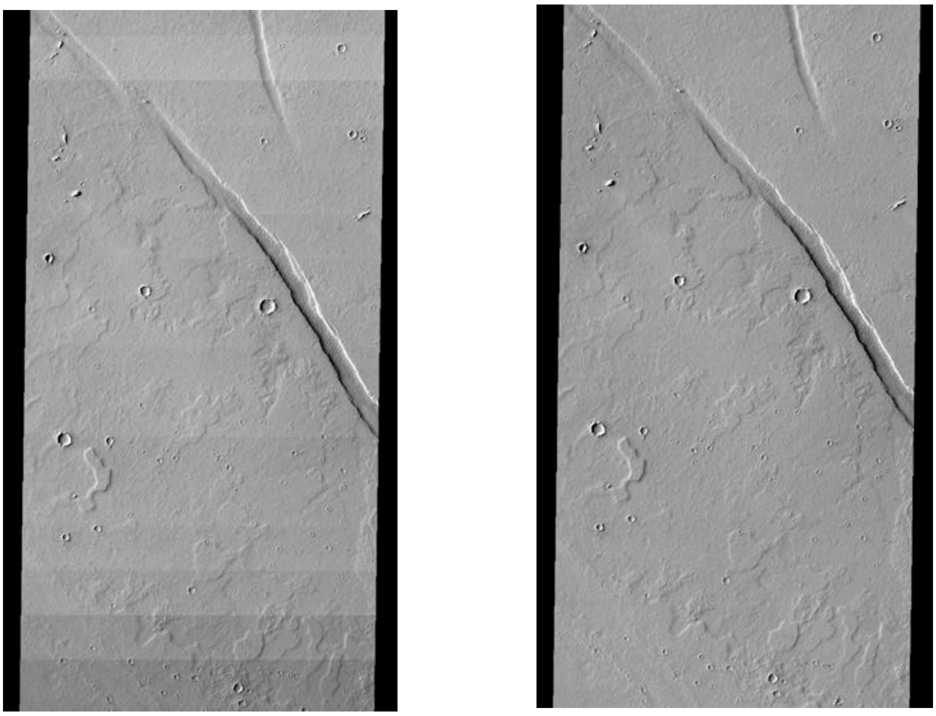

Figure 5: Stitched browse of framelets before framelet to framelet offset correction (left) and after (right). The first framelet is used as a reference for the calibration.

To correct for this, the median difference in pixel values between the overlap region of neighboring framelets is calculated. This difference is then subtracted off all of one of the framelets. This correction uses the first framelet in an exposure sequence as a reference. That is, the second framelet is corrected to have the same bulk brightness as the first framelet, then the third is matched to the second (after the initial correction) etc.

An example image after this calibration is shown in the right panel of Figure 5. A full statistical analysis of this calibration will be included in the CaSSIS Calibration Report.

4.3.5 Partially Processed Data

All images acquired during the nominal science phase mission (post 2019-04-21) are delivered to the PSA as calibrated. However, datasets from the Commissioning, Mars Capture Orbit and In-Orbit Commissioning phases of the mission have not been calibrated with the straylight and framelet to framelet offset correction by UBE. These datasets are therefore classed as partially processed. The image data for each framelet and a corresponding xml label file is delivered by UBE to ESAC. Once the xml file is made PDS4 compatible by the parser, it is ingested into the PSA. Browse/stitched_browse products for this partially processed data are not delivered to the PSA.

4.4 Derived Products

4.4.1 Geometric Calibration

Further geometric correction of calibrated data is made by UBE using a pipeline written and maintained by the University of Arizona. This pipeline incorporates routines from the ISIS environment from the United States Geological Survey (USGS).

The pipeline process includes:

- Map projecting framelets to the surface of Mars.
- Stitching of framelets to create full, map projected, CaSSIS images.
- An improvement to framelet stitching using the ISIS jigsaw routine. Here the position of the spacecraft is altered slightly to improve stitching. This corrects for issues such as spacecraft vibration during a CaSSIS acquisition sequence.
- Images from different filters are combined to make colour images with different filter combinations.

The output from this pipeline includes:

- Map projected stitched CaSSIS images in a single filter, stored as data files with corresponding xml header and browse product.
- Map projected stitched CaSSIS colour images using different combinations of single filter images.
- Smithed spacecraft CK kernel for improved pointing during image acquisition sequence.
- Text file containing map projected corners of image.
- ISIS cube containing image data from each filter.

The pipeline is also designed to interact with the CaST target database. Each image that passes through this pipeline is compared with all CaST targets. If an image satisfies the constraints of the CaST target, then the target is removed from the CaST database, 'retiring' that target.

Data files are output for a full CaSSIS image in each filter (that is, geometric calibration would result in 4 data files being output if all 4 CaSSIS filters were used for image acquisition). Data files are not output for each framelet. A corresponding PDS4 compatible xml file is generated for each data file. Browse products are also produced for each data file and stored as .tiff files.

Browse products for the images where multiple filters have been combined are produced only and stored as .png files. That is, no explicit data files are output with the image data for images with multiple combined filters.

The following products from this pipeline are planned to be delivered to the PSA starting mid-2020 once product PDS4 labels have been finalized:

- Map projected full stitched CaSSIS image (with improved pointing) in each individual filter. Will include image data file, PDS4 xml header and browse product.
- Smithed CK kernel for each image.
- ISIS cubes containing all data – TBC.
- Browse product of full CaSSIS colour images using different filter combinations – TBC.

4.4.2 Stereo Reconstruction

Stereo reconstruction is primarily performed by Osservatorio Astronomico di Padova (OAPD), with support from the German Aerospace Centre (DLR) and the Swiss Federal Institute of Technology Lausanne (EPFL). It is currently beyond the scope of this document to discuss these products. These institutions should be contacted for information about the generation of these products.

5 Data Verification

How the data from each part of the data generation process described in Section 4 is validated is discussed here. Data validation is performed at UBE by the CaSSIS downlink team unless otherwise stated.

5.1 Instrument Health Verification TM

Housekeeping telemetry is output from the UBE pipeline as IDL structure files along with graphical output for specific housekeeping variables (Section 4.3.1). An example output for the motor position is shown in Figure 6. Using the graphical output of housekeeping variables, validators confirm that housekeeping telemetry shows that CaSSIS was operating within expected variable ranges during an operational period. Checks are also made that there are no missing HK packets (i.e. no gaps in the data). Validators also use the IDL structure files for a greater analysis of variables if deemed necessary.

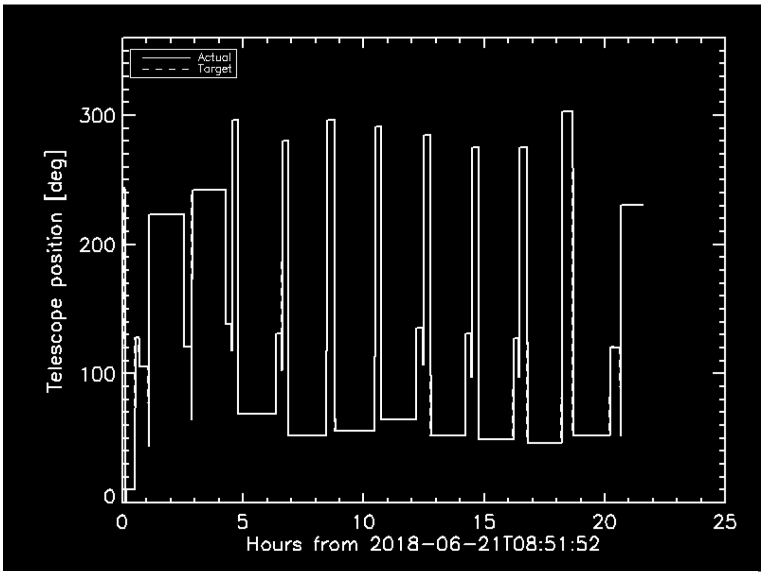

Figure 6: Telescope position as a function of time output from UBE IDL data generation pipeline.

5.2 Command TM Verification

Telecommands sent to CaSSIS are extracted and saved to a report file and IDL structure by the UBE pipeline (Section 4.3.2). Validators check the report file to see if the expected series of commands were sent to CaSSIS. The time the command was sent, the sequence value, the command value and the human readable command is collected in this report file respectively.

The IDL structure file is used by validators for further analysis of the telecommands sent to CaSSIS during an observation period if necessary.

5.3 Raw Data Verification

Raw data refers to CaSSIS image data before any calibrations have been applied (Section 4.3.3). A report file is generated during generation of raw data with the UBE pipeline which states if there are missing packets after extraction from a given science file. Validators check these report files to see if there are any missing packets and whether there are any images that are missing. A summary of one of these reports is shown below:

Image missing at execution time = 2016-11-26T22:36:35.888 Next image is 2016-11-26T22:38:43.646
2016-11-26T22:32:05.000 is INCOMPLETE.
Missing framelet at sequence 38 , window 0
2016-11-26T22:35:34.888 seems complete.
2016-11-26T22:38:38.000 seems complete.

2016-11-26T22:41:11.000 seems complete.
2016-11-26T22:50:17.000 seems complete.
2016-11-26T22:57:29.000 seems complete.
2016-11-26T23:13:15.000 seems complete.

If a packet is missing this means that a framelet in a given filter is missing in a given imaging sequence (i.e. 1 packet = 1 framelet in a specific filter only). Missing packets are rare. It is currently under investigation by the CaSSIS team whether missing packets are due to an in-flight acquisition error, or an error in packet extraction from a science file during the data generation pipeline process.

It should be noted that for rare cases where a framelet is missing in a given CaSSIS image, the rest of the image is still calibrated and ingested into the PSA. Identifying if an image in the PSA has a missing framelet is discussed in Section 6.6.

5.4 Calibrated Data Verification

Calibrated data refers to raw data that has been fully calibrated using the UBE pipeline (Section 4.3.4). Stitched browse products are produced with calibrated data using SPICE kernels. Validators use the stitched browse products to identify any issues arising from the calibration process. Notably, validators check visually whether the straylight and framelet brightness offset correction has been applied correctly. Report files detailing the straylight and offset correction are produced by the UBE pipeline for further analysis if necessary.

Validators also check how well individual framelets have stitched together, which in turn allows checks on the alignment of the telescope to be made.

Validators also periodically perform a detailed visual analysis of stitched images to identify any new bad pixels (Section 4.3.4.3). It should be noted that the CaSSIS team sees no evidence of missing data from any pixels, due to an error in either in-flight writing of pixel data to memory or data being lost in the data calibration process, apart from potentially if binning was used (Section 4.3.4.4). Users of CaSSIS data from the PSA therefore should not need to check pixels for missing data unless binning was used.

5.5 Geometric Calibration Validation

Geometrically calibrated data is calibrated data that has been map projected, with framelets being stitched together for a given filter to make a single image (Section 4.4.1). The stitching is improved through ISIS routines. Colour images with different filter combinations are also created.

Validators visually check to see if the map projection for all framelets in a given image is consistent. Framelet stitching is also visually checked, especially when framelets of different filters are combined to see if there is any colour mis-registration between the filters. The geometric calibration pipeline itself also alerts validators via email if a given CaSSIS image fails to run through any part of the pipeline. A full error report is included in this email for validator follow up.

Checks to see if expected CaST targets are retired by a given image are also made. This process is currently undergoing testing and is planned to be fully implemented by mid 2020.

6 PSA Content and File Identifier conventions

6.1 PSA Bundle Overview

The default logical structure for archiving data in the PSA in PDS4 is through a bundle. A bundle can be thought of as the top level of a directory structure containing all data for a given instrument/data source. For each mission, the PSA requires bundles to be either Mission/Host Data, SPICE Data or Instrument Data and hence all data from an individual instrument on a spacecraft is contained in one bundle i.e. all CaSSIS data is contained within one CaSSIS bundle. Note "data" is defined here is the broadest digital sense and can include documents, ancillary data and supporting calibration data. By PSA convention an instrument bundle is named by mission acronym_host acronym_instrument acronym. For CaSSIS the adopted bundle name is **em16_tgo_cas**.

All PDS4 products are required to have separate xml labels. As the bundle is itself a product, it has a label which is physically located in the top level bundle directory. By convention this label file is named **bundle_em16_tgo_cas.xml**. This label file also serves as a bundle inventory listing the contents of the bundle. Bundles may optionally contain readme files. Again by convention the simple ASCII text readme file which appears in the top level bundle directory is named **readme_em16_tgo_cas.txt**. This file is intended to introduce the bundle and its contents.

6.2 Collections

Within a bundle, data is grouped into collections. Collections act as subdirectories within a bundle, with a given collection containing a certain data type. These subdirectories in turn may have any number of further subdirectories down to a physical level containing basic products.

The collections used for CaSSIS are:

- Data_Raw
- Data_Partially_Processed
- Data_Calibrated
- Data_Derived
- Browse
- Calibration
- Document

- XML schema

The contents of each collection is described below. Like bundles, collections are required to have label files. They are also required to have separate inventory files. The label file is an xml file which gives a description of the collection and some metadata describing the collection.

The inventory file lists all products within the collection and a data collection inventory file may have hundreds of thousands of entries. The inventory file has two columns. The first column will contain either "P" or "S" and this denotes whether the listed product is a primary or secondary member of the collection. All primary members are physically present in the collections. Secondary members are used to reference products in other collections. The second column lists the logical identifier of the product. CaSSIS logical identifiers are described in Section 6.5.

The PSA naming convention for the collection label files is *collection_collection name.xml* and for inventory files *collection_collection name.csv* e.g. the CaSSIS raw data collection label and inventory files are named **collection_data_raw.xml** and **collection_data_raw.csv.**

6.2.1 Data_Raw Collection

The Data_Raw collection contains the raw CaSSIS framelet data produced by ESAC, with corresponding PDS4 compatible xml files that reflect the labels produced by UBE (Section 4.3.3). The framelet image data is stored as a data file, using 4-byte floating points in a 2D array stored as an unformatted binary.

An ASCII format .tab file is also created for each framelet, which contains information about variables included in the xml header file. The format of this data table file is given in Section 6.11. Each framelet therefore has three corresponding files in the Data_Raw collection: the image data file, corresponding PDS4 xml header file and a data table file.

The Data_Raw collection also contains HK TM generated by ESAC. A HK product file contains HK data between two dates. There are 7 types of HK product files, corresponding to the 7 possible types of CaSSIS HK data as described in Section 4.3.1. Each HK product consists of a PDS4 compatible xml file and an ASCII-format content file which lists the variables that can be catalogued in the TM for the given HK type.

The naming convention of science files in the Data_Raw collection is given in Section 6.6. For HK raw data, the naming convention of files is given in Section 6.7. The format of the subdirectory structure is given in Section 6.4.

A description of the labels used for the science raw data and HK raw data are given in Section 7.

As noted in Section 5.3, for rare cases where an image acquisition sequence has a missing framelet, the rest of the framelets are ingested into the PSA. Images with a missing framelet are most easily identified through the absence of an expected file name in the PSA. This is discussed further in Section 6.6.

6.2.2 Data_Partially_Processed Collection

The Data_Partially_Processed collection would contain CaSSIS products delivered to the PSA that had only been partially calibrated. All images acquired during the nominal science phase mission are delivered to the PSA as calibrated. However pre-science phase datasets (before 2018-04-21) have not been fully calibrated (see Section 4.3.5). The Data_Partially_Processed Collection contains these products. Each framelet is stored using 4-byte floating points in a 2D array stored in an unformatted binary, each with a corresponding PDS4 compatible xml file. A data table file is also included for each product in the same way as data in the Data_Raw collection.

6.2.3 Data_Calibrated Collection

The Data_Calibrated collection contains the calibrated products descripted in Section 4.3.4 that are delivered to the PSA by UBE. Similarly to the Data_Raw collection, three file types exist in this collection for each framelet: the framelet data file, the corresponding PDS4 compatible xml file and the data table file that explains variables used in the xml file. The framelet image data is stored as a data file, using 4-byte floating points in a 2D array stored as an unformatted binary.

The stitched browse images of calibrated data delivered by UBE described in Section 4.3.4 is also contained in this collection. That is, the stitched browse product for calibrated data is *not* included in the browse collection, but is included in the Data_Calibrated collection. Why this is the case is discussed in Section 6.3.

The stitched browse product consists of a JPG file, an xml file which contains the geometric information of the product and a second xml file which contains a reference to the first xml file which contains the geometric information. The reason for having two xml files to describe a single product is described in Section 6.3.

The subdirectory structure and filenames used in this collection are described in Section 6.4, 6.6 and 6.9. Information is given here on identifying rare CaSSIS images that have a missing framelet.

6.2.4 Data_Derived Collection

The content of the Data_Derived collection is currently empty. Here it is planned that products produced by the geometric calibration pipeline (Section 4.4.1) will be present. Geometrically calibrated products are planned to start to be supplied to the PSA mid-2020.

6.2.5 Browse Collection

Browse products for each raw framelet generated by ESAC are stored in this collection. As discussed above, it is important to note that the stitched browse products of the calibrated data supplied by UBE are not stored in this collection, but in the Data_Calibrated collection instead. Why this is the case is discussed in Section 6.3.

No browse products are available for any partially processed data.

Each browse product of raw data in this collection consists of a png file and corresponding PDS4 compatible xml label file, with information that points to the original data product in the Raw_Data collection. The filename structure of such files is described in Section 6.9.

6.2.6 Calibration Collection

The Calibration collection contains the bias and flat frames used by UBE during the calibration process. These two files each consist of a data file and a corresponding PDS4 compatible xml file. The image data is stored as 4-byte floating points in a 2D unformatted binary array. The pixel dimensions of the bias/flat are equal to the full CaSSIS detector window of 2048x2048 pixels.

6.2.7 Document Collection

The document collection contains all the archived CaSSIS documents including the EAICD.

6.2.8 XML_Schema Collection

The XML_schema collection contains the files used to define the CaSSIS metadata.

6.3 Browse vs. Stitched_browse Products on the PSA

As noted in Section 4.3.4, a browse product is loosely defined as the browse product for a single framelet in a single filter. A stitched_browse product is a browse product of all the framelets from a given imaging sequence in a given filter stitched together. That is, the stitched_browse product is the browse product of the entire image swath in a given filter.

Browse products are only produced for the raw data (Section 4.3.3) and stitched_browse products are only produced for the calibrated data (Section 4.3.4).

The browse product and image data for raw data products make up five files, following standard PSA convention:

- dat file containing image data for framelet – stored in Raw_Data collection.
- xml file associated with dat file. Contains geometrical information relating to framelet acquisition – stored in Raw_Data collection.
- tab file associated with dat file. Contains description of variables used in xml file. – stored in Raw_Data collection.
- png file for the browse product of the framelet – stored in Browse collection.
- xml file associated with png file – stored in the Browse collection. This does not contain geometrical information pertaining to the framelet acquisition. Instead this file contains a reference to the framelet product in the Raw_Data collection, where the geometrical information can be found.

It is important to note here that the xml file associated with the browse product does *not* contain geometry information and only a reference to the data product where this information can be found. There is also a 1-1 mapping between browse product and raw data product on the PSA (1 raw data framelet = 1 browse product).

The stitched_browse products do not follow this convention. This is because the calibrated image data associated with the stitched_browse product is not delivered to the PSA. The calibrated image data is delivered to the PSA as framelets only. The stitched_browse product with an associated xml file containing the geometrical information is delivered by UBE to the PSA. It is important to note that the geometrical information in this file is that of the first framelet in the associated filter only. For the geometrical information of the entire image swath, information from the first and last framlets should be used (see Section 8).

To maintain PSA convention, the stitched_browse product has a corresponding xml file which contains a reference to where the geometrical information of the product can be found. This geometrical information is then stored in a separate xml file.

For calibrated data therefore, the following products exist:

- dat files containing image data for each calibrated framelet – stored in Data_Calibrated collection.
- xml file containing geometrical information for that specific framelet – stored in Data_Calibrated collection.
- tab file containing description of variables used in the xml file – stored in Data_Calibrated collection.
- jpg file for the stitched_browse product – stored in the Data_Calibrated collection.
- xml file associated with the jpg file, containing reference to where the geometrical information can be found – stored in the Data_Calibrated collection
- xml file associated with the jpg file that contains the geometrical information. This is the xml file of the stitched_browse product supplied to the PSA by UBE (once it has gone through ESAC's parser to make it PDS4 compatible) – stored in the Data_Calibrated collection.

It was judged to be more informative to supply stitched_browse products to the PSA, rather than browse products for individually calibrated framelets. PSA users can quickly view the entire calibrated swath of a given imaging sequence, rather than looking at framelets individually.

The naming conventions of both browse and stitched_browse products are given in Section 6.9 and 6.10 respectively. Finding which calibrated framelets are shown in a stitched_browse product is discussed in Section 8.

6.4 Collection Subdirectories

The PSA adopts a convention that data collections are split by mission phase, beyond this any split is mission specific. ExoMars 2016 has adopted the convention that data is split into groups of 100 orbits then by orbit.

Science products for CaSSIS are further split into filter then observation. An example CaSSIS data collection subdirectory structure is shown in Figure 7.

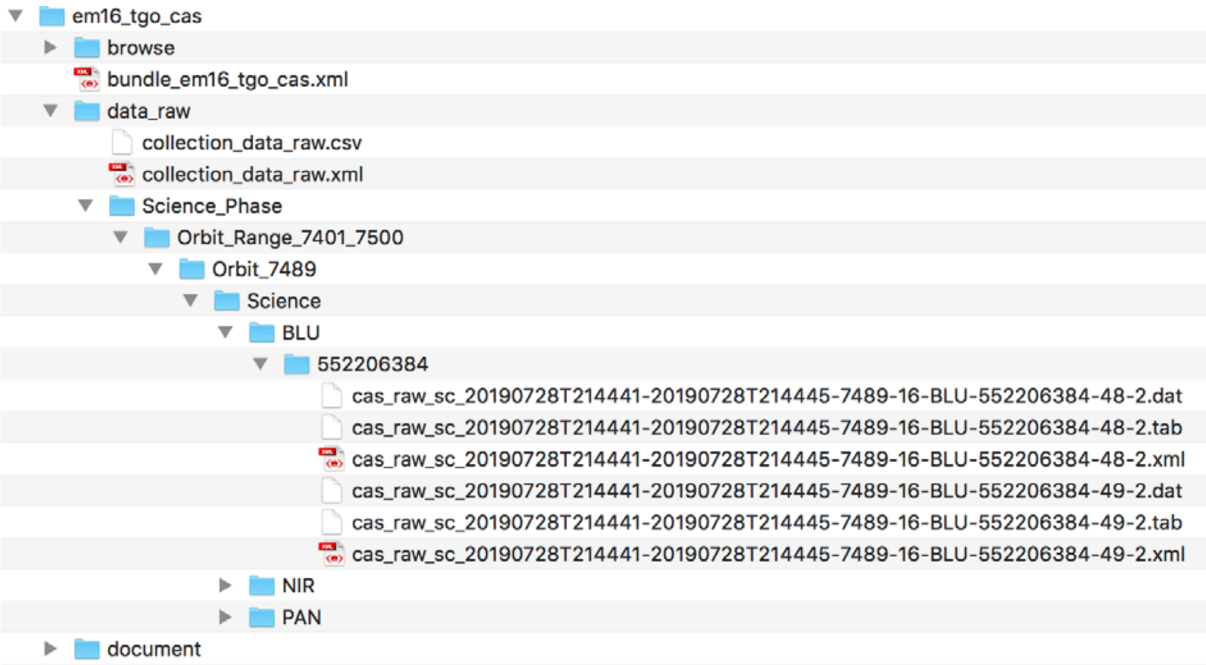

Figure 7: The subdirectory of the CaSSIS bundle on the PSA.

6.5 CaSSIS PDS4 Logical Identifier Naming Convention

Every bundle, collection and product in PDS is assigned an identifier that allows it to be uniquely identified across the system. This identifier is referred to as Logical Identifier (LID). Logical identifiers are constructed as four fields (for a bundle), five fields (for a collection) or six fields (for a basic product), as defined below, with colons delimiting the fields and must be lower case.

For the CaSSIS bundle the LID is:

- urn:esa:psa:em16_tgo_cas

For collections the LIDs are:

- urn:esa:psa:em16_tgo_cas:data_raw
- urn:esa:psa:em16_tgo_cas:data_partially_processed
- urn:esa:psa:em16_tgo_cas:data_calibrated
- urn:esa:psa:em16_tgo_cas:data_derived
- urn:esa:psa:em16_tgo_cas:browse
- urn:esa:psa:em16_tgo_cas:calibration
- urn:esa:psa:em16_tgo_cas:document
- urn:esa:psa:em16_tgo_cas:xml_schema

For products the LIDs are:

- urn:esa:psa:em16_tgo_cas:<collection_identifier>:<***product_identifier***>

Where the product identifier is itself defined by the following convention:

<***product_identifier***> = ***<instrument>_<processing_level>_<type>_<descriptor>***

Where:

- ***<instrument>***, in this case is 'cas'.
- ***<processing_level>*** , is either 'raw', 'par', 'cal' or 'der' for raw, partially processed, calibrated and derived data respectively.
- ***<type>***
  - For primary products equal to hk or sc, for housekeeping and science data respectively.
  - For supplementary products equal to calib, thumb, qla, geo, doc or misc.
- ***<descriptor>*** For Raw and Calibrated science data in the PSA, the descriptor contains:
  - Observation start and end time in UTC, with a time format of <YYYYMMDDThhmmss>.
  - Orbit number.
  - Observation number (from uplink science file name).
  - CaSSIS Filter: pan, nir, red, blu, ex1 (no filter)
  - CaSSIS Image ID.
  - Sequence number: sub-exposure in sequence.
  - Window number: Filter number used (1-6). Note that the 6 windows refer to 4 filters plus 2 control windows described in Section 3.4.

A version identifier can be appended to any logical identifier, at any data level allowing different versions of the same product to be referenced uniquely. For example, the logical identifier for a bundle, collection and data product respectively with an appended ***<version_id>*** would look as follows:

- urn:esa:psa:<bundle_identifier>***::<version_id>***
- urn:esa:psa:<bundle_identifier>:<collection_identifier>***::<version_id>***
- urn:esa:psa:<bundle_identifier>:<collection_identifier>:<product identifier>***::<version_id>***

6.6 Science Products Naming Convention

The raw, calibrated and partially processed CaSSIS products stored on the PSA follow the LID naming convention:

cas_<type>_sc_YYYYMMDDThhmmss-YYYYMMDDThhmmss-CCC-NN-FFF-UID-SEQ-WIN.<ext>

where:

- <type> = raw, cal, par for raw, calibrated and partially processed products respectively.

- YYYY = year, MM = month, DD = day, hh = hour, mm = minute, ss = second. The two times are the beginning and end time in UTC of the full image sequence respectively (see below for details).
- CCC = orbit number
- NN = observation number (from science file name)
- FFF = filter used (BLU, RED, NIR, PAN)
- UID = image id
- SEQ = sequence number (sub-exposure in sequence)
- WIN = Window number (filter used 1-6). Note window 1 and 6 are the control windows described in Section 3.4.
- <ext> = dat, xml, tab for the data xml, and table file respectively.

The beginning and end time in the filename is given to second resolution. However, the time between CaSSIS exposures is roughly 0.3 seconds. The sub-second beginning time of a framelet observation is not used in the filename. The end time in the filename is always taken to be 4 seconds after the beginning time. This difference is included for consistency across all datasets only, it is not representative of the actual end time of a given framelet exposure.

The times used in the filename should therefore not be used for fine time calculations of when a framelet exposure began and finished. The xml file for a given data product contains the actual framelet observation start time to the milli-second level.

For example, in Figure 7 a raw data product is shown with the filename:

cas_raw_sc_20190728T214441-20190728T214445-7489-16-BLU-552206384-48-2.dat,

data type = raw, the beginning time of the observation was at 21:44:41 UTC on July 28th 2019 with the end time being 21:44:45 UTC on July 28th 2019 (subject to the above caveat). The orbit number of the observation was 7489, with an observation number of 16. The BLU filter was used for the observation with an image id of 552206384. The framelet was the 48th in a complete image acquisition using window number 2 (BLU filter). Finally, the file is image data, from the dat extension.

Rare cases where a CaSSIS image has a missing framelet (both in the Raw_Data and Calibrated_Data collections) can be identified by the filename of framelets. Images with missing framelets are ingested into the PSA and maintain the expected filename description. That is, is a framelet is missing, this will result in a sequence number being skipped. For example therefore, if the following framelet data files are present in Data_Raw collection:

…
cas_raw_sc_20190728T214438-20190728T214442-7489-16-BLU-552206384-40-2.dat
cas_raw_sc_20190728T214438-20190728T214442-7489-16-BLU-552206384-41-2.dat
cas_raw_sc_20190728T214439-20190728T214443-7489-16-BLU-552206384-43-2.dat
cas_raw_sc_20190728T214439-20190728T214443-7489-16-BLU-552206384-44-2.dat

…

The jump in sequence number from 41 to 43 indicates that framelet 42 is missing in the BLU filter for this image acquisition. The above example is for data in the Data_Raw collection. However, the same applies for data in the Data_Calibrated collection.

6.7 HK TM Naming Convention

The HK TM stored on the PSA has the following naming convention:

cas_raw_hk_hk<TM_type>_YYYYMMDDThhmmss-YYYYMMDDThhmmss.<ext>,

where the dates are the same format used for science products and describe the date range of contained HK TM data. The <TM_type> refers to the hexid of the integer describing each of the CaSSIS HK frame types described in Section 4.3.1. The <ext> can be either xml or tab, referring to the xml definition file and the ASCII-format content file respectively.

6.8 Calibration Files Naming Convention

Two calibration files are archived by UBE on the PSA (Section 6.2.6): the bias and flat frame. The filenames of these files respectively are:

- cas_calibration_bias_short_190313_2.0.dat
- cas_calibration_flat_field_190313_2.0.dat

Where the date is in YYMMDD format and describes when the calibration file was generated. The trailing number is the version id. The .dat is replaced with xml for the corresponding PDS4 label file.

6.9 Browse Products Naming Convention

Browse products for raw data in the Browse collection follow the same naming convention as the science product itself, but with an additional 'browse' keyword after the '_sc_' keyword (Section 6.6).

In Section 6.6 the following example for a raw data product was given:

cas_raw_sc_20190728T214441-20190728T214445-7489-16-BLU-552206384-48-2.dat.

The corresponding browse product in the Browse collection would be:

cas_raw_sc_browse_20190728T214441-20190728T214445-7489-16-BLU-552206384-48-2.png,
cas_raw_sc_browse_20190728T214441-20190728T214445-7489-16-BLU-552206384-48-2.xml,

for the browse product and xml file that references the product in the Data_Raw collection respectively. For a given browse product therefore, the framelet in the Data_Raw collection can be referenced either using the almost identical filename, or the fact that the xml file of the browse product references the original data product.

6.10 Stitched_browse Products Naming Convention

Stitched_browse products do not share the same naming convention as browse products. Stitched_browse products are not browse products for a single framelet, but many stitched together (Section 4.3.4). Because of this stitched_browse products are stored in a different way to conventional browse products (Section 6.3). Stitched_browse products are also only found in the Data_Calibrated collection and not the Browse collection.

Each stitched browse product consists of a jpg image, an xml file that contains the geometrical information pertaining to the image acquisition and an xml file that references the file that contains the geometrical information (to keep PSA convention, see Section 6.3).

These three file types have the respective file naming convention:

- cas_cal_sc_browse_YYYYMMDDThhmmss-YYYYMMDDThhmmss- FFF- UID-sti.jpg
- cas_cal_sc_YYYYMMDDThhmmss-YYYYMMDDThhmmss- FFF- UID-sti.xml
- cas_cal_sc_browse_YYYYMMDDThhmmss-YYYYMMDDThhmmss- FFF- UID-sti.xml,

where the first time is the beginning time in the filename of the first framelet used in the stitched_browse product. The second time is the end time in the filename of the last framelet used in the stitched_browse product. FFF and UID are the filter and image unique ID.

For example, if the data files for the first and last calibrated framelet of a given imaging sequence in the BLU filter respectively are:

cas_cal_sc_20190728T214423-20190728T214427-7489-16-BLU-552206384-00-2.dat
cas_cal_sc_20190728T214441-20190728T214445-7489-16-BLU-552206384-49-2.dat.

The above stitched_browse products would have the respective filenames:

cas_cal_sc_browse_20190728T214423-20190728T214445-BLU-552206384-sti.jpg
cas_cal_sc_20190728T214423-20190728T214445-BLU-552206384-sti.xml
cas_cal_sc_browse_20190728T214423-20190728T214445-BLU-552206384-sti.xml.

Note that the UID in filename of the stitched_browse product and the constituent calibrated framelets is the same. This allows individual calibrated framelets to be mapped to the associated stitched_browse product.

Mapping calibrated framelets to the associated stitched_browse product is discussed in further detail in Section 8.

6.11 Data Table File Contents

The data table contained in the ASCII-format .tab file for raw and calibrated image data contains definitions of variables. It contains the following format shown in Table 2.

Parameter	Description
TIMESTAMP_TAG	Unique tag indicating timestamp parameter
TIMESTAMP_LENGTH	Length of timestamp parameter in bytes
TIMESTAMP	Timestamp (on-board instrument time) when the appropriate window data was exactly read from PE
UID_TAG	Unique tag of image command
UID_LENGTH	Length in bytes of unique id of image command
UID	Unique id of the appropriate take image command or a random number if it was not specified
WINDOWCOUNTER_TAG	Unique tag of window counter param
WINDOWCOUNTER_LENGTH	Length of window counter in bytes
WINDOWCOUNTER	Number of the actual PE window (1-6) where the data was taken from
SEQUENCECOUNTER_TAG	Unique tag indicating beginning of sequence counter
SEQUENCECOUNTER_LENGTH	Length in bytes of sequence counter
SEQUENCECOUNTER	Sequence counter of the actual exposure
COMPRESSIONRATIO_TAG	Unique tag indicating compression ratio in TM packet
COMPRESSIONRATIO_LENGTH	Length in bytes of compression ratio parameter
COMPRESSIONRATIO	id of the applied compression ratio (0-6)
TOTALDATALENGTH_TAG	Unique tag indicating beginning of total data length
TOTALDATALENGTH_LENGTH	Length in bytes of total data length
TOTALDATALENGTH	Number of bytes in the actual compressed window
OFFSET_TAG	Unique tag indicating offset parameter
OFFSET_LENGTH	Length of offset length in bytes
OFFSET	Offset (inside the total data length area) where the actual data

Parameter	Description
	starts from in bytes
TYPE_TAG	Unique tag of frame type
TYPE_LENGTH	Length of frame type parameter in bytes
TYPE	Type of the frame: 0: science, 1: memory dump, 2: parameter table dump
ERROR_TAG	Unique tag of error code in tm packet
ERROR_LENGTH	Length of error code in bytes
ERROR	Error codes for the current window of the current exposure
POSITION_TAG	Unique tag indicating beginning of motor position
POSITION_LENGTH	Length in bytes of motor position
POSITION	Telescope absolute position at the time of exposure
EXPOSURETIMESTAMP_TAG	Unique tag of acquisition time in tm packet
EXPOSURETIMESTAMP_LENGTH	Length of exposure time in bytes
EXPOSURETIMESTAMP	time (on-board instrument time) of exposure
PEHK_TAG	Unique tag indicating beginning of HK frame
PEHK_LENGTH	Length in bytes of HK frame
PEHK: PE HK frame, provided by PE	HK frame
DATA_TAG	Unique tag indicating data in TM packet
DATA_LENGTH	Length in bytes of data from TM packet
MD_HASH	md5 hash footprint of the packet

Table 2: Data table file for raw and calibrated data on the PSA.

7 PSA CaSSIS PDS4 Labels

All PDS4 products must include a detached highly prescribed xml label file. This label may describe one or more data products but it is usually the case that a label is describing only one product. All CaSSIS labels with one exception describe one product, this includes document products, browse products, calibration products and most science products. The exception is the raw level science data where the table file and the framelet image are described by a single label.

PDS has adopted the terminology of "attributes" to describe single xml tags containing an item of metadata. Attributes are grouped into classes, and classes are also grouped into higher level classes. The top level grouping is the product class and almost all science data will use the Product_Observational class with Product_Document, Product_Browse and Product_Ancillary (e.g. for calibration data) also in common use.

Depending on the product class used there is a specific set of subclasses, known as "Areas" which are either optional or required. For Product_Observational these are:

- Identification_Area (mandatory)
- Observation_Area (mandatory)
- Reference_List (optional)
- File_Area_Observational (mandatory)
- File_Area_Supplemental (optional)

For other products only a sub-set of these is required. CaSSIS science products include all these classes except File_Area_Supplemental.

7.1 Top Level Classes in Product_Observational

Examples of each area in the Product_Observational class is given here. The example entries for each of these areas is taken from the label of a calibrated data xml file. The example entries also are applicable to the contents of an xml file for raw data. Entries which refer to the calibration steps are removed however, with relevant entries being changed to reflect the raw product. Classes here also reflect those used in labels for HK TM data (referred to in Section 7.4).

7.1.1 Identification_Area

The Identification_Area provides basic information about the product including its LID, version and history:

```
<Identification_Area>
    <logical_identifier>urn:esa:psa:em16_tgo_cas:data_calibrated:cas_cal_sc_20180518t235728-20180518t235732-2161-26-nir-272862380-39-1</logical_identifier>
    <version_id>2.0</version_id>
    <title>CaSSIS experiment</title>
    <information_model_version>1.11.0.0</information_model_version>
    <product_class>Product_Observational</product_class>
    <Citation_Information>
      <author_list>Nicolas Thomas</author_list>
      <publication_year>2019</publication_year>
      <description>Produced at the Physikalisches Inst., Universitaet Bern (UBE)</description>
    </Citation_Information>
    <Modification_History>
      <Modification_Detail>
        <modification_date>2019-12-06</modification_date>
        <version_id>2.0</version_id>
        <description>First version</description>
      </Modification_Detail>
    </Modification_History>
  </Identification_Area>
```

7.1.2 Observation_Area

The Observation_Area itself consists of several classes:

- Time_Coordinates
- Primary_Result_Summary
- Investigation_Area
- Observing_System
- Target_Identification
- Mission_Area
- Discipline_Area

7.1.2.1 Time_Coordinates

This class is used to simply specify the start and end date/time of the observation in UTC. Note the end time is always 4 seconds after the start time and is not the actual end time of the observation. The local Martian solar time of the observation is also given.

```
<Time_Coordinates>
    <start_date_time>2018-05-18T23:57:28.928Z</start_date_time>
    <stop_date_time>2018-05-18T23:57:32.928Z</stop_date_time>
    <local_true_solar_time>15:11:39</local_true_solar_time>
</Time_Coordinates>
```

7.1.2.2 Primary_Result_Summary

This class provides a top level description of the science area the product is in. The PSA requires this area to be filled in as aspects such as wavelength are then utilised for the PSA filter menu and search.

```
<Primary_Result_Summary>
    <purpose>Science</purpose>
    <processing_level>Raw</processing_level>
    <description>Summary of Results</description>
    <Science_Facets>
      <wavelength_range>Visible</wavelength_range>
      <domain>Surface</domain>
      <discipline_name>Imaging</discipline_name>
    </Science_Facets>
</Primary_Result_Summary>
```

7.1.2.3 Investigation_Area

Investigation in PDS relates to the mission, ground based facility etc., hence this area provides the mission name and a link to the mission context file which gives more detailed information about the mission.

```
<Investigation_Area>
    <name>ExoMars 2016</name>
    <type>Mission</type>
    <Internal_Reference>
      <lid_reference>urn:esa:psa:context:investigation:mission.em16
      </lid_reference>
      <reference_type>data_to_investigation</reference_type>
    </Internal_Reference>
</Investigation_Area>
```

7.1.2.4 *Observing_System*

This class is used to describe the instrument. As the ExoMars 2016 mission has two hosts, the TGO and the EDM, the TGO as the CaSSIS host is also described with both the host and the instrument referencing their respective context files.

```
<Observing_System>
        <description>Observing System for TGO+CASSIS</description>
        <Observing_System_Component>
          <name>TGO</name>
          <type>Spacecraft</type>
          <description>Instrument Host</description>
          <Internal_Reference>
            <lid_reference>urn:esa:psa:context:instrument_host:spacecraft.tgo
            </lid_reference>
            <reference_type>is_instrument_host</reference_type>
          </Internal_Reference>
        </Observing_System_Component>
        <Observing_System_Component>
          <name>CaSSIS</name>
          <type>Instrument</type>
          <description>Colour and Stereo Surface Imaging System
            (CaSSIS) on the Exomars Trace Gas Orbiter which is a
            push-frame cmos visible reflecting telescope
          </description>
          <Internal_Reference>
            <lid_reference>urn:esa:psa:context:instrument:cassis.tgo
            </lid_reference>
            <reference_type>is_instrument</reference_type>
          </Internal_Reference>
        </Observing_System_Component>
</Observing_System>
```

7.1.2.5 *Target_Identification*

Science (Product_Observational) files require a target to be specified along with a link to the relevant PDS context file. All CaSSIS observations made after Mars arrival have target Mars specified. Other targets such as sky darks etc were used during cruise phase.

```
<Target_Identification>
        <name>MARS</name>
        <type>Planet</type>
        <description>Planet Mars</description>
        <Internal_Reference>
          <lid_reference>urn:nasa:pds:context:target:planet.mars</lid_reference>
          <reference_type>data_to_target</reference_type>
        </Internal_Reference>
 </Target_Identification>
```

7.1.2.6 Mission_Area

This area contains all the CaSSIS specific metadata attributes and classes. In the PDS all attributes and classes are defined in dictionaries. The top level classes described above are all defined in the PDS core dictionary also known as the information model. This dictionary can be extended at discipline level via the discipline dictionaries and/or at mission level by one or more mission dictionaries. Anything defined in a mission level dictionary appears in this area and, as is the case for CaSSIS, it is not unusual for the bulk of information in the label to be in this area.

In addition to dictionaries files (schema files), other files containing sets of rules for the attributes may also be produced. These rules files are known as schematron files. Schema files always end .xsd and schematron files .sch.

As the PSA is a cross mission archive, a mission level schema and schematron exist and the PSA classes are used to provide information which is actually relevant cross-mission but for which no classes yet exist in the PDS core dictionary. When PSA classes are used these are always prefixed by psa. By internal PSA convention the PSA classes/attributes are filled in at the start of the Mission_Area.

The areas within the *Mission_Area* for CaSSIS are as follows:

- Mission_Information
- Sub-Instrument
- Observation_Context
- Processing_Context
- CaSSIS_Data

7.1.2.6.1 Mission_Information

This area contains what phase of the mission the observation was acquired (entries given in Section 2) and the orbit number of the observation.

```
<psa:Mission_Information>
        <psa:mission_phase_name>Science Phase</psa:mission_phase_name>
        <psa:mission_phase_identifier>psp</psa:mission_phase_identifier>
        <psa:start_orbit_number>2161</psa:start_orbit_number>
        <psa:stop_orbit_number>2161</psa:stop_orbit_number>
</psa:Mission_Information>
```

7.1.2.6.2 Sub-Instrument

Area contains basic information CaSSIS.

```
<psa:Sub-Instrument>
        <psa:identifier>SCI</psa:identifier>
        <psa:name>CASSIS Science</psa:name>
```

<psa:type>Imager</psa:type>
</psa:Sub-Instrument>

7.1.2.6.3 Observation_Context

Area contains information on if any special pointing was used for observation (e.g. targeted observation, see Section 4.1.2). Currently however, the pointing description is set to no pointing. The correct pointing description (nadir/targeted) will be included in this label at a TBC time. This area also contains the unique id of the observation.

<psa:Observation_Context>
<psa:instrument_pointing_mode>No pointing</psa:instrument_pointing_mode>
<psa:instrument_pointing_description>No pointing</psa:instrument_pointing_description>
<psa:observation_identifier>272862380</psa:observation_identifier>
</psa:Observation_Context>

7.1.2.6.4 Processing_Context

Contains an entry for every part of the processing applied to the data by UBE (Section 4.3.4). Calibration of data is performed according to Section 4.3.4. The names of the calibration steps in the processing context area follow internal UBE naming conventions. This is not applicable for PSA users.

<psa:Processing_Context>
<psa:processing_software_title>Radiometric Pipeline</psa:processing_software_title>
<psa:processing_software_version>v1.01</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>Header_Creation: c_new_header (2019-10-22T18:26:47)</psa:processing_software_title>
<psa:processing_software_version>V3.2 (16-Feb-2017)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>SC TM Conversion: c_sc_file_resolution (2019-10-22T18:26:47)</psa:processing_software_title>
<psa:processing_software_version>V1.5 (22-Mar-2018)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>Mechanism HK validity flag set: c_rot_mechanism_validity (2019-10-22T18:26:47)</psa:processing_software_title>
<psa:processing_software_version>V1.0 (02-May-2019)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>SC TM Conversion: c_batch_sc_tm_packets (2019-10-22T18:26:48)</psa:processing_software_title>

<psa:processing_software_version>V1.38 (04-Sep-2019)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>Bias Subtraction (bias_short_190313.dat): c_remove_bias (2019-10-22T18:38:29)</psa:processing_software_title>
<psa:processing_software_version>V1.13 (13-Mar-2019)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>Flat field removal (flat_field_190313.dat): c_remove_flat (2019-10-22T18:38:29)</psa:processing_software_title>
<psa:processing_software_version>V1.14 (13-Mar-2019)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>Bad pixel removal (nothing to do): c_remove_badpix (2019-10-22T18:38:29)</psa:processing_software_title>
<psa:processing_software_version>V1.01 (03-Apr-2019)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>Expansion: c_expand (2019-10-22T18:38:29)</psa:processing_software_title>
<psa:processing_software_version>V1.1 (null)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>Absolute_Calibration: c_absolute_calibration (2019-10-22T18:38:29)</psa:processing_software_title>
<psa:processing_software_version>V1.1 (null)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>SC TM Conversion: c_top_batch_level0tolevel1a (2019-10-22T18:38:29)</psa:processing_software_title>
<psa:processing_software_version>V1.14 (03-Apr-2019)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>Command_Verification: c_top_batch_level1atolevel1 (2019-10-22T18:44:18)</psa:processing_software_title>
<psa:processing_software_version>V1.11 (null)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>Photometric_correction: c_correct_straylight_level1 (2019-10-22T18:54:25)</psa:processing_software_title>
<psa:processing_software_version>V2.03 (null)</psa:processing_software_version>
</psa:Processing_Context>
<psa:Processing_Context>
<psa:processing_software_title>EM16 Data Processing System</psa:processing_software_title>
<psa:processing_software_version>3.2-RC3</psa:processing_software_version> </psa:Processing_Context>

7.1.2.6.5 CaSSIS_Data

This area contains most of the specific variables generated by CaSSIS that pertain to the image acquisition. This area contains both fixed values relating to standard CaSSIS variables and those specific to the image acquisition. A short description is given after each entry below where necessary. Entries described as 'N/A' are variables applicable to the CaSSIS operations team only.

<em16_tgo_cas:Cassis_Data>
<em16_tgo_cas:Instrument_Information>
<em16_tgo_cas:instrument_ifov>1.142E-5</em16_tgo_cas:instrument_ifov>
<em16_tgo_cas:instrument_ifov_unit>rad/px</em16_tgo_cas:instrument_ifov_unit>
<em16_tgo_cas:filters_available>BLU RED NIR PAN</em16_tgo_cas:filters_available>
</em16_tgo_cas:Instrument_Information>
<em16_tgo_cas:HK_Derived_Data>
<em16_tgo_cas:onboard_image_acquisition_time>2018-05-18T23:57:28.928Z</em16_tgo_cas:onboard_image_acquisition_time> *Exact time of acquisition of observation.*

<em16_tgo_cas:onboard_acquisition_sclk_time>6.878312964793E7</em16_tgo_cas:onboard_acquisition_sclk_time>
<em16_tgo_cas:mission_phase>M01</em16_tgo_cas:mission_phase> *MTP of observation.*
<em16_tgo_cas:filter>NIR</em16_tgo_cas:filter>
<em16_tgo_cas:telescope_rotation_angle>261.157</em16_tgo_cas:telescope_rotation_angle> *Angle of rotation of CaSSIS in degrees. 0 degrees is where CaSSIS is pointing in the same direction as the front of the spacecraft. Angle increases as CaSSIS rotates clockwise.*
<em16_tgo_cas:compression_name>JPEG-LS</em16_tgo_cas:compression_name>
<em16_tgo_cas:actual_compression_ratio>3.152</em16_tgo_cas:actual_compression_ratio>
<em16_tgo_cas:requested_compression_ratio>3.014</em16_tgo_cas:requested_compression_ratio>
<em16_tgo_cas:isis_unique_id>M0120180518235728928NIR0103900</em16_tgo_cas:isis_unique_id> *ID of observation that is: <MTP><image_time><filter><window_number><exposure_number>*
<em16_tgo_cas:ctf_unique_id>MY34_002161_299_0</em16_tgo_cas:ctf_unique_id> *Unique ID given to all framelets in a given imaging sequence. <Martian_year><Orbit_number><ascending_node><image_type (0 = individual, 1 = first of stereo pair, 2 = second of stereo pair)>.*
<em16_tgo_cas:expanded>1</em16_tgo_cas:expanded>
<em16_tgo_cas:Saturation_analysis>
<em16_tgo_cas:percent_FW_95>0.0</em16_tgo_cas:percent_FW_95>*Percentage of pixels that exceed 95% of maximum value.*
</em16_tgo_cas:Saturation_analysis>
<em16_tgo_cas:absolute_calibration>120.6</em16_tgo_cas:absolute_calibration>*Factor to convert D/N to I/F.*
</em16_tgo_cas:HK_Derived_Data>
<em16_tgo_cas:PEHK_Derived_Data>
<em16_tgo_cas:address_accessed>3</em16_tgo_cas:address_accessed> *N/A*
<em16_tgo_cas:address_contents>0</em16_tgo_cas:address_contents> *N/A*
<em16_tgo_cas:assumed_roic_frequency>5000000.0</em16_tgo_cas:assumed_roic_frequency> *N/A*
<em16_tgo_cas:binning_window_1>0</em16_tgo_cas:binning_window_1> *Binning used (0 = none, 1 = 2x2, 2= 4x4, 3 = 8x8)*
<em16_tgo_cas:binning_window_2>0</em16_tgo_cas:binning_window_2>
<em16_tgo_cas:binning_window_3>0</em16_tgo_cas:binning_window_3>

<em16_tgo_cas:binning_window_4>0</em16_tgo_cas:binning_window_4>
<em16_tgo_cas:binning_window_5>0</em16_tgo_cas:binning_window_5>
<em16_tgo_cas:binning_window_6>0</em16_tgo_cas:binning_window_6>
<em16_tgo_cas:detector_status>1</em16_tgo_cas:detector_status> *N/A*
<em16_tgo_cas:exposure_time>0.001469</em16_tgo_cas:exposure_time> *Observation exposure time in seconds*
<em16_tgo_cas:last_event>0</em16_tgo_cas:last_event> *N/A*
<em16_tgo_cas:number_of_windows>2</em16_tgo_cas:number_of_windows> *Number of windows used for this observation. Gives number of filters used in exposure.*
<em16_tgo_cas:protection_flag>0</em16_tgo_cas:protection_flag> *N/A*
<em16_tgo_cas:spare1>0</em16_tgo_cas:spare1> *N/A*
<em16_tgo_cas:spare2>0</em16_tgo_cas:spare2> *N/A*
<em16_tgo_cas:spare3>0</em16_tgo_cas:spare3> *N/A*
<em16_tgo_cas:status_word>1</em16_tgo_cas:status_word> *N/A*
<em16_tgo_cas:tec_control_byte0>0</em16_tgo_cas:tec_control_byte0> *N/A*
<em16_tgo_cas:tec_control_byte1>0</em16_tgo_cas:tec_control_byte1> *N/A*
<em16_tgo_cas:tec_control_byte2>0</em16_tgo_cas:tec_control_byte2> *N/A*
<em16_tgo_cas:tec_control_byte3>0</em16_tgo_cas:tec_control_byte3> *N/A*
<em16_tgo_cas:tec_control_byte4>0</em16_tgo_cas:tec_control_byte4> *N/A*
<em16_tgo_cas:tec_control_byte5>0</em16_tgo_cas:tec_control_byte5> *N/A*
<em16_tgo_cas:tec_control_byte6>0</em16_tgo_cas:tec_control_byte6> *N/A*
<em16_tgo_cas:tec_control_byte7>0</em16_tgo_cas:tec_control_byte7> *N/A*
<em16_tgo_cas:tec_control_byte8>0</em16_tgo_cas:tec_control_byte8> *N/A*
<em16_tgo_cas:tec_control_byte9>0</em16_tgo_cas:tec_control_byte9> *N/A*
<em16_tgo_cas:tec_current>0</em16_tgo_cas:tec_current> *N/A*
<em16_tgo_cas:tec_status>0</em16_tgo_cas:tec_status> *N/A*
<em16_tgo_cas:t_ch1>0</em16_tgo_cas:t_ch1> *N/A*
<em16_tgo_cas:t_ch2>0</em16_tgo_cas:t_ch2> *N/A*
<em16_tgo_cas:t_fpa1>2740</em16_tgo_cas:t_fpa1> *Temperature of focal plane assembly in milli-degrees, sensor 1.*
<em16_tgo_cas:t_fpa2>2737</em16_tgo_cas:t_fpa2> *Temperature of focal plane assembly in milli-degrees, sensor 2.*
<em16_tgo_cas:t_pe>2656</em16_tgo_cas:t_pe> *Temperature of proximity electronics in milli-degrees.*
<em16_tgo_cas:test_status>0</em16_tgo_cas:test_status> *N/A*
<em16_tgo_cas:v25_loss_flag>0</em16_tgo_cas:v25_loss_flag> *N/A*
<em16_tgo_cas:v75_loss_flag>0</em16_tgo_cas:v75_loss_flag> *N/A*
<em16_tgo_cas:vdet_ana_ovc>0</em16_tgo_cas:vdet_ana_ovc> *N/A*
<em16_tgo_cas:vdet_dig_ovc>0</em16_tgo_cas:vdet_dig_ovc> *N/A*
<em16_tgo_cas:v_pe33>3447</em16_tgo_cas:v_pe33> *N/A*
<em16_tgo_cas:window1_end_col>2047</em16_tgo_cas:window1_end_col> *N/A*
<em16_tgo_cas:window1_end_row>967</em16_tgo_cas:window1_end_row> *N/A*
<em16_tgo_cas:window1_start_col>0</em16_tgo_cas:window1_start_col> *N/A*
<em16_tgo_cas:window1_start_row>712</em16_tgo_cas:window1_start_row> *N/A*
<em16_tgo_cas:window2_end_col>2047</em16_tgo_cas:window2_end_col> *N/A*
<em16_tgo_cas:window2_end_row>1303</em16_tgo_cas:window2_end_row> *N/A*
<em16_tgo_cas:window2_start_col>0</em16_tgo_cas:window2_start_col> *N/A*
<em16_tgo_cas:window2_start_row>1048</em16_tgo_cas:window2_start_row> *N/A*

<em16_tgo_cas:window3_end_col>63</em16_tgo_cas:window3_end_col> *N/A*
<em16_tgo_cas:window3_end_row>-1</em16_tgo_cas:window3_end_row> *N/A*
<em16_tgo_cas:window3_start_col>0</em16_tgo_cas:window3_start_col> *N/A*
<em16_tgo_cas:window3_start_row>0</em16_tgo_cas:window3_start_row> *N/A*
<em16_tgo_cas:window4_end_col>63</em16_tgo_cas:window4_end_col> *N/A*
<em16_tgo_cas:window4_end_row>-1</em16_tgo_cas:window4_end_row> *N/A*
<em16_tgo_cas:window4_start_col>0</em16_tgo_cas:window4_start_col> *N/A*
<em16_tgo_cas:window4_start_row>0</em16_tgo_cas:window4_start_row> *N/A*
<em16_tgo_cas:window5_end_col>63</em16_tgo_cas:window5_end_col> *N/A*
<em16_tgo_cas:window5_end_row>-1</em16_tgo_cas:window5_end_row> *N/A*
<em16_tgo_cas:window5_start_col>0</em16_tgo_cas:window5_start_col> *N/A*
<em16_tgo_cas:window5_start_row>0</em16_tgo_cas:window5_start_row> *N/A*
<em16_tgo_cas:window6_end_col>63</em16_tgo_cas:window6_end_col> *N/A*
<em16_tgo_cas:window6_end_row>-1</em16_tgo_cas:window6_end_row> *N/A*
<em16_tgo_cas:window6_start_col>0</em16_tgo_cas:window6_start_col> *N/A*
<em16_tgo_cas:window6_start_row>0</em16_tgo_cas:window6_start_row> *N/A*
</em16_tgo_cas:PEHK_Derived_Data>
<em16_tgo_cas:Telescope_Information>
<em16_tgo_cas:focal_length>0.876</em16_tgo_cas:focal_length> *CaSSIS focal length.*
<em16_tgo_cas:focal_length_unit>M</em16_tgo_cas:focal_length_unit>
<em16_tgo_cas:f_number>6.49</em16_tgo_cas:f_number>
<em16_tgo_cas:telescope_type>Three-mirror anastigmat with powered fold mirror</em16_tgo_cas:telescope_type>
</em16_tgo_cas:Telescope_Information>
<em16_tgo_cas:Detector_Information>
<em16_tgo_cas:cassis_description>2D Array</em16_tgo_cas:cassis_description>
<em16_tgo_cas:pixel_height>10.0</em16_tgo_cas:pixel_height> *For entire detector window.*
<em16_tgo_cas:pixel_height_unit>MICRON</em16_tgo_cas:pixel_height_unit>
<em16_tgo_cas:pixel_width>10.0</em16_tgo_cas:pixel_width> *For entire detector window.*
<em16_tgo_cas:pixel_width_unit>MICRON</em16_tgo_cas:pixel_width_unit>
<em16_tgo_cas:detector_type>SI CMOS HYBRID (OSPREY 2K)</em16_tgo_cas:detector_type>
<em16_tgo_cas:read_noise>61.0</em16_tgo_cas:read_noise>
<em16_tgo_cas:read_noise_unit>ELECTRON</em16_tgo_cas:read_noise_unit>
</em16_tgo_cas:Detector_Information>
<em16_tgo_cas:Geometry_Information>
<em16_tgo_cas:tgo_off_nadir_angle>0.012</em16_tgo_cas:tgo_off_nadir_angle> *Angle between TGO boresight and nadir in degrees.*
<em16_tgo_cas:cassis_off_nadir_angle>9.981</em16_tgo_cas:cassis_off_nadir_angle> *Angle between CaSSIS and nadir in degrees.*
<em16_tgo_cas:phase_angle_filter>71.404</em16_tgo_cas:phase_angle_filter> *degrees.*
<em16_tgo_cas:incidence_angle_filter>69.551</em16_tgo_cas:incidence_angle_filter> *degrees*
<em16_tgo_cas:emission_angle_filter>10.729</em16_tgo_cas:emission_angle_filter> *degrees.*
<em16_tgo_cas:tgo_ground_track_velocity>2.979</em16_tgo_cas:tgo_ground_track_velocity> *km/s.*

<em16_tgo_cas:predicted_maximum_exposure_time>1.4737</em16_tgo_cas:predicted_maximum_exposure_time> *milliseconds.*

<em16_tgo_cas:predicted_required_repetition_frequency>339.5</em16_tgo_cas:predicted_required_repetition_frequency> *milliseconds.*
<em16_tgo_cas:sub_cassis_longitude>30.576865</em16_tgo_cas:sub_cassis_longitude>
<em16_tgo_cas:sub_cassis_latitude>-56.985665</em16_tgo_cas:sub_cassis_latitude>
<em16_tgo_cas:forward_rotation_angle_required>-98.762</em16_tgo_cas:forward_rotation_angle_required> *Angle between front of TGO and CaSSIS motor position in degrees.*

<em16_tgo_cas:spice_kernel_misalignment_predict>0.674</em16_tgo_cas:spice_kernel_misalignment_predict> *Angle between neighboring framelets, need for stitching of framelets accurately.*
<em16_tgo_cas:cassis_ground_track_velocity>2.9769</em16_tgo_cas:cassis_ground_track_velocity> *km/s.*
<em16_tgo_cas:pixel_scale_image_plane>4.39</em16_tgo_cas:pixel_scale_image_plane> *m/px.*
<em16_tgo_cas:tgo_ground_track_vector_x>1.1707</em16_tgo_cas:tgo_ground_track_vector_x> *km/s*
<em16_tgo_cas:tgo_ground_track_vector_y>2.3789</em16_tgo_cas:tgo_ground_track_vector_y> *km/s*
<em16_tgo_cas:tgo_ground_track_vector_z>1.3582</em16_tgo_cas:tgo_ground_track_vector_z> *km/s*
<em16_tgo_cas:cassis_ground_track_vector_x>1.1646</em16_tgo_cas:cassis_ground_track_vector_x> *km/s*
<em16_tgo_cas:cassis_ground_track_vector_y>2.3476</em16_tgo_cas:cassis_ground_track_vector_y> *km/s*
<em16_tgo_cas:cassis_ground_track_vector_z>1.4122</em16_tgo_cas:cassis_ground_track_vector_z> *km/s*
<em16_tgo_cas:cassis_ground_track_fsa_vector_x>-0.0115</em16_tgo_cas:cassis_ground_track_fsa_vector_x> *km/s*
<em16_tgo_cas:cassis_ground_track_fsa_vector_y>-0.982</em16_tgo_cas:cassis_ground_track_fsa_vector_y> *km/s*
<em16_tgo_cas:cassis_ground_track_fsa_vector_z>0.1885</em16_tgo_cas:cassis_ground_track_fsa_vector_z> *km/s*
<em16_tgo_cas:pixel_scale_surface>4.4667</em16_tgo_cas:pixel_scale_surface> *m/px.*
<em16_tgo_cas:l_sub_s>177.969</em16_tgo_cas:l_sub_s>
<em16_tgo_cas:sun_angle_from_cassis_detector_plane>-18.575</em16_tgo_cas:sun_angle_from_cassis_detector_plane> *degrees.*

<em16_tgo_cas:sun_azimuth_wrt_cassis_detector_frame>257.913</em16_tgo_cas:sun_azimuth_wrt_cassis_detector_frame> *degrees.*
<em16_tgo_cas:beta_angle>68.513</em16_tgo_cas:beta_angle> *degrees.*
<em16_tgo_cas:line_of_sight_distance>383.823</em16_tgo_cas:line_of_sight_distance> *km.*

<em16_tgo_cas:spacecraft_direction_with_respect_to_node>ASCENDING</em16_tgo_cas:spacecraft_direction_with_respect_to_node>
<em16_tgo_cas:cassis_image_type>0</em16_tgo_cas:cassis_image_type> *type of image, 0 = individual image, 1 = first of stereo pair, 2 = second of stereo pair.*
<em16_tgo_cas:sun_elevation_on_minus_y>-20.465</em16_tgo_cas:sun_elevation_on_minus_y> *degrees.*
<em16_tgo_cas:sun_azimuth_on_minus_y>270.003</em16_tgo_cas:sun_azimuth_on_minus_y> *degrees.*
</em16_tgo_cas:Geometry_Information>
<em16_tgo_cas:Image_Command>
<em16_tgo_cas:parameter_table_ref>2</em16_tgo_cas:parameter_table_ref> *N/A.*
<em16_tgo_cas:t_exp>153</em16_tgo_cas:t_exp> *Exposure time m/s.*
<em16_tgo_cas:num_exp>40</em16_tgo_cas:num_exp> *Number of exposures in observation sequence.*
<em16_tgo_cas:step_exp>337000</em16_tgo_cas:step_exp> *Time between exposures in microseconds.*
<em16_tgo_cas:rioc_freq>0</em16_tgo_cas:rioc_freq> *N/A*

<em16_tgo_cas:num_win>2</em16_tgo_cas:num_win> *Number of windows used in exposure.*
<em16_tgo_cas:bin_win1>0</em16_tgo_cas:bin_win1> *Binning for window 1, 0=none, 1=2x2, 2=4x4, 3=8x8.*
<em16_tgo_cas:bin_win2>0</em16_tgo_cas:bin_win2> *Binning for window 2, 0=none, 1=2x2, 2=4x4, 3=8x8.*
<em16_tgo_cas:bin_win3>0</em16_tgo_cas:bin_win3> *Binning for window 3, 0=none, 1=2x2, 2=4x4, 3=8x8.*
<em16_tgo_cas:bin_win4>0</em16_tgo_cas:bin_win4> *Binning for window 4, 0=none, 1=2x2, 2=4x4, 3=8x8.*
<em16_tgo_cas:bin_win5>0</em16_tgo_cas:bin_win5> *Binning for window 5, 0=none, 1=2x2, 2=4x4, 3=8x8.*
<em16_tgo_cas:bin_win6>0</em16_tgo_cas:bin_win6> *Binning for window 6, 0=none, 1=2x2, 2=4x4, 3=8x8.*
<em16_tgo_cas:win1_str>1424</em16_tgo_cas:win1_str> *N/A.*
<em16_tgo_cas:win1_end>16770960</em16_tgo_cas:win1_end> *N/A.*
<em16_tgo_cas:win2_str>2096</em16_tgo_cas:win2_str> *N/A.*
<em16_tgo_cas:win2_end>16771632</em16_tgo_cas:win2_end> *N/A.*
<em16_tgo_cas:win3_str>0</em16_tgo_cas:win3_str> *N/A.*
<em16_tgo_cas:win3_end>0</em16_tgo_cas:win3_end> *N/A.*
<em16_tgo_cas:win4_str>0</em16_tgo_cas:win4_str> *N/A.*
<em16_tgo_cas:win4_end>0</em16_tgo_cas:win4_end> *N/A.*
<em16_tgo_cas:win5_str>0</em16_tgo_cas:win5_str> *N/A.*
<em16_tgo_cas:win5_end>0</em16_tgo_cas:win5_end> *N/A.*
<em16_tgo_cas:win6_str>0</em16_tgo_cas:win6_str> *N/A.*
<em16_tgo_cas:win6_end>0</em16_tgo_cas:win6_end> *N/A.*
<em16_tgo_cas:pe_test>0</em16_tgo_cas:pe_test> *N/A.*
<em16_tgo_cas:win1_compr>0</em16_tgo_cas:win1_compr> *N/A.*
<em16_tgo_cas:win2_compr>0</em16_tgo_cas:win2_compr> *N/A.*
<em16_tgo_cas:win3_compr>0</em16_tgo_cas:win3_compr> *N/A.*
<em16_tgo_cas:win4_compr>0</em16_tgo_cas:win4_compr> *N/A.*
<em16_tgo_cas:win5_compr>0</em16_tgo_cas:win5_compr> *N/A.*
<em16_tgo_cas:win6_compr>0</em16_tgo_cas:win6_compr> *N/A.*
<em16_tgo_cas:tec_start>0</em16_tgo_cas:tec_start> *N/A.*
<em16_tgo_cas:crc1>28061</em16_tgo_cas:crc1> *N/A.*
<em16_tgo_cas:unique_identifier>272862380</em16_tgo_cas:unique_identifier> *UID of exposure.*
<em16_tgo_cas:coarse_time>0</em16_tgo_cas:coarse_time> *N/A.*
<em16_tgo_cas:fine_time>0</em16_tgo_cas:fine_time> *N/A.*
<em16_tgo_cas:unique_id_decoded>10438CAC</em16_tgo_cas:unique_id_decoded> *N/A.*
</em16_tgo_cas:Image_Command>
<em16_tgo_cas:Producer_Data>
<em16_tgo_cas:product_id>M0120180518235728928NIR0103900</em16_tgo_cas:product_id> *ID of observation that is: <MTP><image_time><filter><window_number><exposure_number>*
<em16_tgo_cas:ctf_id>MY34_002161_299_0</em16_tgo_cas:ctf_id> *Unique ID given to all framelets in a given imaging sequence. <Martian_year><Orbit_number><ascending_node><image_type (0 = individual, 1 = first of stereo pair, 2 = second of stereo pair)>.*
<em16_tgo_cas:stp>004</em16_tgo_cas:stp> *STP*
<em16_tgo_cas:mtp>M001</em16_tgo_cas:mtp> *MTP*
</em16_tgo_cas:Producer_Data>
</em16_tgo_cas:Cassis_Data>

7.1.2.7 Discipline_Area

This area is used to house attributes defined in one of the PDS discipline dictionaries. The PDS organisation is split into discipline nodes and each node produces a dictionary in its area. CaSSIS data labels include attributes defined in the Geosciences dictionary and these are prefixed by "geom". This area contains any kernels used and further geometrical information relating to the image acquisition.

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<geom:spice_kernel_file_name>/ck/em16_tgo_sc_fpp_014_01_20160314_20170315_s20170201_v01.bc</geom:spice_ker
nel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ck/em16_tgo_sc_fsp_094_02_20180222_20191026_s20190928_v01.bc</geom:spice_ker
nel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ck/em16_tgo_sc_scm_20161001_20161031_s20171007_v01.bc</geom:spice_kernel_file
_name>

```
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ck/em16_tgo_sc_spm_20170201_20170228_s20171007_v01.bc</geom:spice_kernel_file
_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ck/em16_tgo_sc_sam_20180304_20180311_s20180215_v01.bc</geom:spice_kernel_file
_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ck/em16_tgo_sc_ssm_20180311_20190101_s20190703_v01.bc</geom:spice_kernel_file
_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ck/em16_tgo_sc_ssm_20190101_20191013_s20190928_v01.bc</geom:spice_kernel_file
_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ck/cassis_ck_p_160312_201231_191024.bc</geom:spice_kernel_file_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
              <geom:spice_kernel_file_name>/fk/em16_tgo_v18.tf</geom:spice_kernel_file_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
              <geom:spice_kernel_file_name>/fk/em16_edm_v01.tf</geom:spice_kernel_file_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
              <geom:spice_kernel_file_name>/fk/em16_tgo_ops_v02.tf</geom:spice_kernel_file_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
              <geom:spice_kernel_file_name>/fk/em16_dsk_surfaces_v00.tf</geom:spice_kernel_file_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
              <geom:spice_kernel_file_name>/fk/rssd0002.tf</geom:spice_kernel_file_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
              <geom:spice_kernel_file_name>/fk/earth_topo_050714.tf</geom:spice_kernel_file_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
              <geom:spice_kernel_file_name>/fk/earthfixediau.tf</geom:spice_kernel_file_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
              <geom:spice_kernel_file_name>/fk/estrack_v01.tf</geom:spice_kernel_file_name>
            </geom:SPICE_Kernel_Identification>
            <geom:SPICE_Kernel_Identification>
              <geom:spice_kernel_file_name>/fk/new_norcia_topo.tf</geom:spice_kernel_file_name>
            </geom:SPICE_Kernel_Identification>
```

<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ik/em16_tgo_acs_v06.ti</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ik/em16_tgo_cassis_v07.ti</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ik/em16_tgo_frend_v05.ti</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ik/em16_tgo_nomad_v04.ti</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ik/em16_tgo_str_v03.ti</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/ik/em16_edm_deca_v00.ti</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/lsk/naif0012.tls</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/pck/pck00010.tpc</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/pck/de-403-masses.tpc</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/sclk/em16_tgo_fict_20180215.tsc</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/sclk/em16_tgo_step_20190928.tsc</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/sclk/em16_edm_fict_20160921.tsc</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/em16_tgo_struct_v01.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/em16_tgo_cog_v01.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/em16_tgo_fsp_048_01_20160314_20181231_v02.bsp</geom:spice_kernel_file_nam
e>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>

<geom:spice_kernel_file_name>/spk/em16_tgo_fsp_065_01_20181120_20190429_v02.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/em16_tgo_fsp_082_01_20190318_20190903_v02.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/em16_tgo_fsp_094_02_20190610_20191123_v01.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/em16_edm_sot_landing_site_20161020_21000101_v01.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/em16_edm_fpd_028_01_20161016_20161020_v01.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/de432s.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/mar097_20160314_20300101.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/new_norcia.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
<geom:SPICE_Kernel_Identification>
<geom:spice_kernel_file_name>/spk/estrack_v01.bsp</geom:spice_kernel_file_name>
</geom:SPICE_Kernel_Identification>
</geom:SPICE_Kernel_Files>
<geom:Image_Display_Geometry>
<geom:Display_Direction>
<geom:comment>Comment TBC</geom:comment>
<geom:horizontal_display_axis>Axis name TBC</geom:horizontal_display_axis>
<geom:horizontal_display_direction>Left to Right</geom:horizontal_display_direction>
<geom:vertical_display_axis>Axis name TBC</geom:vertical_display_axis>
<geom:vertical_display_direction>Top to Bottom</geom:vertical_display_direction>
</geom:Display_Direction>
<geom:Object_Orientation_RA_Dec>
<geom:right_ascension_angle unit="deg">311.2186</geom:right_ascension_angle>
<geom:declination_angle unit="deg">29.5269</geom:declination_angle>
<geom:celestial_north_clock_angle unit="deg">0.0</geom:celestial_north_clock_angle>
<geom:Reference_Frame_Identification>
<geom:name>Name TBC</geom:name>

</geom:Reference_Frame_Identification>
</geom:Object_Orientation_RA_Dec>
</geom:Image_Display_Geometry>
<geom:Geometry_Orbiter>
<geom:geometry_reference_time_utc>2019-12-06T04:10:30.685Z</geom:geometry_reference_time_utc>
<geom:Orbiter_Identification>
<geom:Geometry_Target_Identification>
<geom:body_spice_name>Mars</geom:body_spice_name>
</geom:Geometry_Target_Identification>
</geom:Orbiter_Identification>
<geom:Distances>
<geom:Distances_Specific>
<geom:spacecraft_target_boresight_intercept_distance
unit="km">383.823</geom:spacecraft_target_boresight_intercept_distance>
<geom:spacecraft_heliocentric_distance unit="AU">1.4706342</geom:spacecraft_heliocentric_distance>
<geom:spacecraft_central_body_distance unit="km">3759.7</geom:spacecraft_central_body_distance>
<geom:spacecraft_geocentric_distance unit="AU">0.7037025</geom:spacecraft_geocentric_distance>
</geom:Distances_Specific>
</geom:Distances>
<geom:Surface_Geometry>
<geom:Surface_Geometry_Specific>
<geom:Footprint_Vertices>
<geom:Pixel_Intercept>
<geom:reference_pixel_location>Center</geom:reference_pixel_location>
<geom:pixel_latitude unit="deg">-57.041333</geom:pixel_latitude>
<geom:pixel_longitude unit="deg">30.679685</geom:pixel_longitude>
</geom:Pixel_Intercept>
<geom:Pixel_Intercept>
<geom:reference_pixel_location>Center</geom:reference_pixel_location>
<geom:pixel_latitude unit="deg">-56.96677</geom:pixel_latitude>
<geom:pixel_longitude unit="deg">30.436198</geom:pixel_longitude>
</geom:Pixel_Intercept>
<geom:Pixel_Intercept>
<geom:reference_pixel_location>Center</geom:reference_pixel_location>
<geom:pixel_latitude unit="deg">-56.949893</geom:pixel_latitude>
<geom:pixel_longitude unit="deg">30.453589</geom:pixel_longitude>
</geom:Pixel_Intercept>
<geom:Pixel_Intercept>
<geom:reference_pixel_location>Center</geom:reference_pixel_location>
<geom:pixel_latitude unit="deg">-57.024463</geom:pixel_latitude>
<geom:pixel_longitude unit="deg">30.697135</geom:pixel_longitude>
</geom:Pixel_Intercept>
</geom:Footprint_Vertices>
<geom:subspacecraft_latitude unit="deg">-57.9386</geom:subspacecraft_latitude>
<geom:subspacecraft_longitude unit="deg">29.5523</geom:subspacecraft_longitude>
</geom:Surface_Geometry_Specific>
</geom:Surface_Geometry>

```
            <geom:Illumination_Geometry>
              <geom:Illumination_Specific>
                <geom:reference_location>Target Center</geom:reference_location>
                <geom:phase_angle unit="deg">69.535</geom:phase_angle>
                <geom:solar_elongation unit="deg">110.464</geom:solar_elongation>
              </geom:Illumination_Specific>
            </geom:Illumination_Geometry>
          </geom:Geometry_Orbiter>
        </geom:Geometry>
      </Discipline_Area>
```


7.1.3 Reference_List

The reference list is used to link between PDS4 products using the unique identifier of each. The most common link is between data and browse products but this mechanism can also be used to link to calibration products, input products and even external data such as papers.


```
<Reference_List>
    <External_Reference>
        <reference_text>Thomas, N., Cremonese, G., Banaszkiewicz, M., Bridges, J., Byrne, S., da Deppo, V., Debei, S., El-
Maarry, M. R., et al. The Colour and Stereo Surface Imaging System (CaSSIS) for ESAs Trace Gas Orbiter. 8th Mars
International Conference, 2014. Abstract #1067.</reference_text>
        <description>Paper describing the CaSSIS Instrument</description>
    </External_Reference>
</Reference_List>
```


7.1.4 File_Area_Observational

The File_Area is where the data file is defined. For typical cases of a single label associated with a single data file there are two classes, the file class which includes top level data then the class describing the file and will depend on file type. For CaSSIS the PDS4 class Array_2D_Image is used.


```
<File_Area_Observational>
    <File>
        <file_name>cas_cal_sc_20180518T235728-20180518T235732-2161-26-NIR-272862380-39-1.dat</file_name>
        <local_identifier>cas_cal_sc_20180518T235728-20180518T235732-2161-26-NIR-272862380-39-
1.dat</local_identifier>
        <creation_date_time>2019-10-22T18:54:25</creation_date_time>
        <file_size unit="byte">2097152</file_size>
        <md5_checksum>fca46f1fb7be47230c5cc0542fc77ff7</md5_checksum> N/A.
        <comment>Calibrated Image Data</comment>
    </File>
    <Array_2D_Image>
        <name>CAL_CASSIS_CASSIS</name>
        <offset unit="byte">0</offset>
        <axes>2</axes> 2d array.
        <axis_index_order>Last Index Fastest</axis_index_order>
        <Element_Array>
            <data_type>IEEE754LSBSingle</data_type> N/A.
        </Element_Array>
```

```
        <Axis_Array>
          <axis_name>Line</axis_name>
          <local_identifier>line</local_identifier>
          <elements>256</elements> Number of pixel rows.
          <sequence_number>1</sequence_number> Row.
        </Axis_Array>
        <Axis_Array>
          <axis_name>Sample</axis_name>
          <local_identifier>sample</local_identifier>
          <elements>2048</elements> Number of pixel columns.
          <sequence_number>2</sequence_number> Column.
        </Axis_Array>
      </Array_2D_Image>
    </File_Area_Observational>
```


7.2 Top Level Classes in Product_Browse

Browse product labels contain information to reference the science observation. Both browse and stitched_browse products have such labels (Section 6.3). An example browse label is given below. Classes defined in this label are the same as those defined in Section 7.1. The difference to the label entries showed in Section 7.1 is in the Reference_List class. Here a reference is given to the corresponding science product. The File_Area_Browse class is also present in browse labels. This contains the reference of the png browse product for raw data and jpg image for the stitched_browse product.


```
<Product_Browse xsi:schemaLocation="http://pds.nasa.gov/pds4/pds/v1
http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1B00.xsd http://psa.esa.int/psa/v1
http://psa.esa.int/psa/v1/PDS4_PSA_1101.xsd" xmlns="http://pds.nasa.gov/pds4/pds/v1"
xmlns:psa="http://psa.esa.int/psa/v1" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  <Identification_Area>
    <logical_identifier>urn:esa:psa:em16_tgo_cas:browse:cas_raw_sc_browse_20180518t235728-20180518t235732-
2161-26-nir-272862380-39-1</logical_identifier>
    <version_id>2.0</version_id>
    <title>CaSSIS experiment</title>
    <information_model_version>1.11.0.0</information_model_version>
    <product_class>Product_Browse</product_class>
    <Modification_History>
      <Modification_Detail>
        <modification_date>2019-11-22</modification_date>
        <version_id>2.0</version_id>
        <description>First Version</description>
      </Modification_Detail>
    </Modification_History>
  </Identification_Area>
  <Reference_List>
    <Internal_Reference>
      <lidvid_reference>urn:esa:psa:em16_tgo_cas:data_raw:cas_raw_sc_20180518t235728-20180518t235732-2161-26-
nir-272862380-39-1::2.0</lidvid_reference>
```

```
        <reference_type>browse_to_data</reference_type>
      </Internal_Reference>
    </Reference_List>
    <File_Area_Browse>
      <File>
        <file_name>cas_raw_sc_browse_20180518T235728-20180518T235732-2161-26-NIR-272862380-39-1.png</file_name>
        <local_identifier>cas_raw_sc_browse_20180518t235728-20180518t235732-2161-26-nir-272862380-39-1.png</local_identifier>
        <creation_date_time>2019-11-22T13:56:50.971Z</creation_date_time>
        <file_size unit="byte">394475</file_size>
        <md5_checksum>228723ffe0802874905b012245c9441e</md5_checksum>
      </File>
      <Encoded_Image>
        <offset unit="byte">0</offset>
        <encoding_standard_id>PNG</encoding_standard_id>
      </Encoded_Image>
    </File_Area_Browse>
</Product_Browse>
```


7.3 Top Level Classes in Product_Observational for Stitched_browse

As discussed in Section 6.3, stitched_browse products have an associated file that contains geometrical information pertaining to that image acquisition. All labels are the same as though described in Section 7.1. It is important to note that all the geometrical information in this file uses the time of the first framelet. Image long/lat corners in this file are of the first framelet. To get the corners of the full stitched_browse image, the corners described in the individual xml files of the first and last framelet in that image should be used.

7.4 Top Level Classes in Product_Observational for HK TM

The label for the HK TM contains classes described for science products in Section 7.1. For HK TM the File_Area_Observational class (Section 7.1.4) includes a <*Table_Character*> class which contains an entry for each of the parameters described by the HK. The entry for each variable in the <*Table_Character*> class here is of the following form:

<Field_Character>
<name>ECSN0096</name> *CaSSIS FSW name for this variable*
<field_number>98</field_number> *The variable entry number in the table*
<field_location unit="byte">453</field_location> *Location of variable in HK TM byte stream of returned data*
<data_type>ASCII_Integer</data_type>
<field_length unit="byte">1</field_length> *Length of data for variable*
<description>PWR_STAT_OP</description> *Variable name*
</Field_Character>

The variables returned by the HK TM in the <*description*> entry, for each of the 7 data types (Section 4.3.1), can be found in the FSW archive document (EXM-CA-UMA-UBE-10001). These variables are summarized in Tables given in Section 11.1.

7.5 Top Level Classes in Product_Ancillary

The Product_Ancillary class is used to describe CaSSIS calibration products, namely the bias and flat frame described in Section 4.3.4. In addition to areas described in Section 7.1, this class also uses the <File_Area_Ancillary> area. This area contains a reference to the calibration data product in addition to the size of the product in pixels:

```
<File_Area_Ancillary>
    <File>
      <file_name>cas_calibration_flat_field_190313.dat</file_name>
      <local_identifier>cas_calibration_flat_field_190313.dat</local_identifier>
      <creation_date_time>2019-03-13T12:00:00</creation_date_time>
      <file_size unit="byte">33554432</file_size>
      <md5_checksum>e68a68e05900bdfa127b2a4ca3a14d8c</md5_checksum>
      <comment>Calibration Image Data</comment>
    </File>
    <Array_2D_Image>
      <name>CAL_CASSIS_CASSIS</name>
      <offset unit="byte">0</offset>
      <axes>2</axes>
      <axis_index_order>Last Index Fastest</axis_index_order>
      <Element_Array>
        <data_type>IEEE754LSBDouble</data_type>
      </Element_Array>
      <Axis_Array>
        <axis_name>Line</axis_name> Dimension 1 pixels
        <local_identifier>line</local_identifier>
        <elements>2048</elements>
        <sequence_number>1</sequence_number>
      </Axis_Array>
      <Axis_Array>
        <axis_name>Sample</axis_name> Dimension 2 pixels
        <local_identifier>sample</local_identifier>
        <elements>2048</elements>
        <sequence_number>2</sequence_number>
      </Axis_Array>
    </Array_2D_Image>
  </File_Area_Ancillary>.
```

8 SORTING/GROUPING CASSIS PSA DATA

Different ways of grouping CaSSIS data on the PSA is outlined below. It should be noted that checking for the rare cases where a framelet is missing in a given image acquisition can be done using the method described in Section 6.6.

8.1 Grouping Framelets for Each Image

CaSSIS raw and calibrated data is primarily stored as individual framelets (disregarding the stitched browse products of calibrated data in the Data_Calibrated collection). Which framelets correspond to which image can be sorted in one of the ways described below.

8.1.1 Using PSA directory structure

CaSSIS data is stored in each collection by unique ID (Figure 7). Each imaging sequence has a unique id. All framelets from a given image therefore have the same id. Framelets within the sub-directory of a given unique ID are therefore from the same image sequence.

8.1.2 Using Framelet Filenames

The framelet filename contains the start and end time of the complete image sequence. Taking framelets with an equal start and end time in the filename would correspond to all framelets in that image exposure. Moreover, for framelets sorted in this way, the sequence number in the file name will increase from 0 -> N linearly (assuming no lost framelets), where N is the total number of framelets used for that sequence. Note that for each sequence number, there will be a framelet for each of the filters used for that acquisition.

The framelet filename also contains the image unique ID. This value should be identical for every framelet acquired in a given observing sequence. This value is also used in the filename of the stitched_browse product. This can be used to map stitched_browse images to the constituent calibrated framelets.

Framelets can also be mapped to stitched_browse products using times in the filename. If a framelet has a start time that is between the start and end time used in the filename of a stitched_browse product, then that framelet is part of the stitched_browse product.

8.1.3 Using Framelet xml Labels

In the xml label for each framelet, there is an entry: *<ctf_id>*. This is a unique identifier for a given image acquisition sequence. For example: *<ctf_id>MY34_002177_344_2* refers to an image taken in Martian year 34, on orbit 2177, which had an ascending node of 344deg. The trailing _2 is the image type (discussed below). All framelets associated with this image will have an identical entry in the *<ctf_id>* field.

8.2 Grouping by Image Type

CaSSIS images can either be individual images or stereo pairs. To identify if a framelet on the PSA (in any of the data collections) is an individual image or a stereo pair, the xml file for that framelet must be used.

As stated above each xml label will have an entry <*ctf_id*>. The last number in this entry is either 0, 1 or 2. Images with 0 are individual image, images with 1 are the first image in a stereo pair (image taken in front of the spacecraft) and images with 2 are the second image in a stereo pair (image taken behind the spacecraft).

Framelets that are part of a stereo pair may roughly also be identified using observation start and end time in the filename. The first and second images in a stereo pair are separated by roughly 45sec. Checking which framelets have the end time and start time in the filename separated by 45sec gives a good indicator that this was a stereo pair.

9 PSA Delivery Schedule

Raw and partially processed data acquired during pre-science phase operations (Commissioning, Mars Capture Orbit and In-Orbit Commissioning) have been delivered to the PSA.

Science phase Raw and Calibrated data is in the process of being ingested into the PSA and data acquired during a given month aims to be ingested six months after acquisition.

Post 2020, derived products (geometrically corrected data) aims to be ingested into the PSA at the same rate.

Raw, calibrated and derived products all plan to also be made publically available directly through UBE. The timeline for publically accessible data is TBD and is dependent on progress of required infrastructure (websites etc.).

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11 APPENDICES

11.1 HK variable description

Parameter	Description
PUS_TIME_UTC	Packet Utilization Standard time (UTC)
PUS_TIME	Packet Utilization Standard Time (Spacecraft clock time)
ECSN0001: TM_IDENTIFIER_0	Value used to define a housekeeping packet
ECSN0002: TM_DISCRIMINATOR_0	Value defining housekeeping packet frame type
ECSN0003: TM_TIME_PREAMBLE_0	Redundant value used to pad time value
ECSN0004: TM_TIME_COARSE_0	Time of window acquisition to second precision
ECSN0005: TM_TIME_FINE_0	Time of window acquisition to millisecond precision
ECSN0006: TM_TIME_0	CaSSIS clock timestamp of window acquisition
ECSN0007: PT_DPM (raw)	Processer temperature
ECSN0008: PT_PE_2 (raw)	Proximity electronics temperature sensor 2
ECSN0009: PT_PE_1 (raw)	Proximity electronics temperature sensor 1
ECSN0010: PT_FPA_1 (raw)	Focal plane assembly temperature sensor 1
ECSN0011: PT_FPA_2 (raw)	Focal plane assembly temperature sensor 2
ECSN0012: PT_TEL_M1_1 (raw)	Telescope Mirror 1 (Thomas et al. 2017) temperature sensor 1
ECSN0013: PT_TEL_M1_2 (raw)	Telescope Mirror 1 (Thomas et al. 2017) temperature sensor 2
ECSN0014: PT_TEL_RB_1 (raw)	Telescope Rear Baffle (Thomas et al. 2017) temp sensor 1
ECSN0015: PT_TEL_RB_2 (raw)	Telescope Rear Baffle (Thomas et al. 2017) temp sensor 2
ECSN0016: PT_TEL_M2 (raw)	Telescope Mirror 2 (Thomas et al. 2017) temperature
ECSN0017: PT_TEL_FB (raw)	Telescope Front Baffle (Thomas et al. 2017) temperature
ECSN0018: PT_PCM_5V (raw)	Power supply 5V DC/DC board temperature
ECSN0019: PT_PCM_PE (raw)	Proximity electronics board temperature

Parameter	Description
ECSN0020: PT_RCM (raw)	RCM Board temperature
ECSN0021: PT_PCM_MOT (raw)	Motor board temperature
ECSN0022: PT_MOT_1 (raw)	Step Motor temperature sensor 1
ECSN0023: PT_MOT_2 (raw)	Step Motor temperature sensor 2
ECSN0024: TSENS_H_STAT	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK.
ECSN0056: HEATER_H_STAT_FSW	Heater health status. The 16 bit word contains the health status bit for each heater. 0: heater failed, 1: heater OK.
ECSN0072: PE_RED_SENSOR	Proximity electronics redundant heater sensor status
ECSN0073: PE_MAIN_SENSOR	Proximity electronics main heater sensor status
ECSN0074: PE_RED_RUN	Proximity electronics redundant heater running flag
ECSN0075: PE_MAIN_RUN	Proximity electronics main heater running flag
ECSN0076: FPA_RED_SENSOR	Focal plane assembly redundant heater sensor status flag
ECSN0077: FPA_MAIN_SENSOR	Focal plane assembly main heater sensor status flag
ECSN0078: FPA_RED_RUN	Focal plane assembly redundant heater running flag
ECSN0079: FPA_MAIN_RUN	Focal plane assembly main heater running flag
ECSN0080: M1_RED_SENSOR	Rear baffle redundant mirror sensor status
ECSN0081: M1_MAIN_SENSOR	Rear baffle main heater mirror sensor status
ECSN0082: RB_RED_SENSOR	Rear baffle redundant heater sensor status
ECSN0083: RB_MAIN_SENSOR	Rear baffle main heater sensor status
ECSN0084: RB_RED_RUN	Rear baffle redundant heater running
ECSN0085: RB_MAIN_RUN	Rear baffle main heater running
ECSN0086: M2_RED_SENSOR	Front baffle redundant mirror sensor status
ECSN0087: M2_MAIN_SENSOR	Front baffle main heater mirror sensor status
ECSN0088: FB_RED_SENSOR	Front baffle redundant heater sensor status
ECSN0089: FB_MAIN_SENSOR	Front baffle main heater sensor status
ECSN0090: FB_RED_RUN	Front baffle redundant heater running
ECSN0091: FB_MAIN_RUN	Front baffle main heater running
ECSN0092: RCM_RED_SENSOR	RCM Redundant Heater Sensor Status
ECSN0093: RCM_MAIN_SENSOR	RCM Main Heater Sensor Status
ECSN0094: RCM_RED_RUN	RCM Redundant Heater Running
ECSN0095: RCM_MAIN_RUN	RCM Main Heater Running

Parameter	Description
ECSN0096: PWR_STAT_OP	Operational Power On
ECSN0097: PWR_STAT_RED	Redundant Power On
ECSN0098: PWR_STAT_NOM	Nominal Power On

Table 3: Information contained in housekeeping packet frame type 0 (temperature information).

Parameter	Description
PUS_TIME_UTC	Packet Utilization Standard time (UTC)
PUS_TIME	Packet Utilization Standard Time (Spacecraft clock time)
ECSN0101: TM_IDENTIFIER_1	Value used to define a housekeeping packet
ECSN0102: TM_DISCRIMINATOR_1	Value defining housekeeping packet frame type
ECSN0103: TM_TIME_PREAMBLE_1	Redundant value used to pad time value
ECSN0104: TM_TIME_COARSE_1	Time of window acquisition to second precision
ECSN0105: TM_TIME_FINE_1	Time of window acquisition to millisecond precision
ECSN0106: TM_TIME_1	CaSSIS clock timestamp of window acquisition
ECSN0107: Z1_CALC_TEMP (raw)	Zone 1 (proximity electronics) temperature
ECSN0108: Z2_CALC_TEMP (raw)	Zone 2 (focal plane assembly) temperature
ECSN0109: Z3_CALC_TEMP (raw)	Zone 3 (mirror 1) temperature
ECSN0110: Z4_CALC_TEMP (raw)	Zone 4 (mirror 2) temperature
ECSN0111: Z5_CALC_TEMP (raw)	Zone 5 (RCM board) temperature
ECSN0112: Z1_MIN_TEMP (raw)	Zone 1 (Proximity electronics) target temperature min
ECSN0113: Z2_MIN_TEMP (raw)	Zone 2 (Focal plane assembly) target temperature min
ECSN0114: Z3_MIN_TEMP (raw)	Zone 3 (mirror 1) target temperature min
ECSN0115: Z4_MIN_TEMP (raw)	Zone 4 (mirror 2) target temperature min
ECSN0116: Z5_MIN_TEMP (raw)	Zone 5 (RCM board) target temperature min
ECSN0117: Z1_MAX_TEMP (raw)	Zone 1 (Proximity electronics) target temperature max
ECSN0118: Z2_MAX_TEMP (raw)	Zone 2 (Focal plane assembly) target temperature max
ECSN0119: Z3_MAX_TEMP (raw)	Zone 3 (mirror 1) target temperature max
ECSN0120: Z4_MAX_TEMP (raw)	Zone 4 (mirror 2) target temperature max
ECSN0121: Z5_MAX_TEMP (raw)	Zone 5 (RCM board) target temperature max
ECSN0122: Z31_CALC_TEMP (raw)	Zone 3 (rear baffle) temperature
ECSN0123: Z41_CALC_TEMP (raw)	Zone 4 (front baffle) temperature
ECSN0124: Z31_MIN_TEMP (raw)	Zone 3 (rear baffle) target temperature min
ECSN0125: Z41_MIN_TEMP (raw)	Zone 4 (front baffle) target temperature min

Parameter	Description
ECSN0126: Z31_MAX_TEMP (raw)	Zone 3 (rear baffle) target temperature max
ECSN0127: Z41_MAX_TEMP (raw)	Zone 4 (front baffle) target temperature max
ECSN0128: ZMOT_CALC_TEMP (raw)	Motor temperature

Table 4: Information contained in housekeeping packet frame type 1 (CaSSIS zone temperature information).

Parameter	Description
PUS_TIME_UTC	Packet Utilization Standard time (UTC)
PUS_TIME	Packet Utilization Standard Time (Spacecraft clock time)
ECSN0201: TM_IDENTIFIER_2	Value used to define a housekeeping packet
ECSN0202: TM_DISCRIMINATOR_2	Value defining housekeeping packet frame type
ECSN0203: TM_TIME_PREAMBLE_2	Redundant value used to pad time value
ECSN0204: TM_TIME_COARSE_2	Time of window acquisition to second precision
ECSN0205: TM_TIME_FINE_2	Time of window acquisition to millisecond precision
ECSN0206: TM_TIME_2	CaSSIS clock timestamp of window acquisition
ECSN0207: U_0V5_REF (raw)	0.5V Reference Voltage
ECSN0208: I_3V3_DPM (raw)	Current on 3.3V processor supply
ECSN0209: U_3V3_DPM (raw)	3.3V of processor
ECSN0210: I_1V8 (raw)	Current of 1.8V Processor Supply
ECSN0211: U_1V8 (raw)	1.8V Processor Core Voltage
ECSN0212: U_5V_OP (raw)	5V Operating Voltage
ECSN0213: U_5V_ANA (raw)	5V Analogue Voltage
ECSN0214: I_5V_ANA (raw)	Current of 5V Analogue Voltage
ECSN0215: I_3V3_FPGA (raw)	Current of 3.3V FPGA Voltage
ECSN0216: U_3V3_FPGA (raw)	3.3V FPGA Voltage
ECSN0217: I_1V2_FPGA (raw)	Current of 1.2V FPGA Voltage
ECSN0218: U_1V2_FPGA (raw)	1.2V FPGA Voltage
ECSN0219: U_24V_MOT_1 (raw)	24V Motor DC/DC No. 1 Voltage
ECSN0220: U_24V_MOT_2 (raw)	24V Motor DC/DC No. 2 Voltage
ECSN0221: U_3V3_PE (raw)	PE Digital 3.3V Voltage
ECSN0222: I_3V3_PE (raw)	PE Digital 3.3V Current
ECSN0223: U_8V5_PE (raw)	PE Detector Positive +8.5V Voltage
ECSN0224: I_8V5_PE (raw)	PE Detector Positive +8.5V Current
ECSN0225: U_N_8V5_PE (raw)	PE Detector Negative -8.5V Voltage

Parameter	Description
ECSN0226: I_N_8V5_PE (raw)	PE Detector Negative -8.5V Current
ECSN0227: U_25V_PE (raw)	PE Detector Bias +25V Voltage
ECSN0228: I_25V_PE (raw)	PE Detector Bias +25V Current

Table 5: Information contained in housekeeping packet frame type 2 (voltages and currents information).

Parameter	Description
PUS_TIME_UTC	Packet Utilization Standard time (UTC)
PUS_TIME	Packet Utilization Standard Time (Spacecraft clock time)
ECSN0301: TM_IDENTIFIER_3	Value used to define a housekeeping packet
ECSN0302: TM_DISCRIMINATOR_3	Value defining housekeeping packet frame type
ECSN0303: TM_TIME_PREAMBLE_3	Redundant value used to pad time value
ECSN0304: TM_TIME_COARSE_3	Time of window acquisition to second precision
ECSN0305: TM_TIME_FINE_3	Time of window acquisition to millisecond precision
ECSN0306: TM_TIME_3	CaSSIS clock timestamp of window acquisition
ECSN0307: PE_HK_DETECTOR_TESTMODE	Commanded test mode. 0: no test mode; 1: test mode.
ECSN0308: PE_HK_COM_TEC_STAT	Commanded TEC status. 0: off, 1: on.
ECSN0309: PE_HK_DETECTOR_ON	Commanded detector status. 0: off, 1: on.
ECSN0310: PE_HK_LASTVENT	PE HK Last event
ECSN0311: PE_HK_ADDRRW	PE HK Address read/written
ECSN0312: PE_HK_ADDRRW_CONT	PE HK Address read/written content
ECSN0313: PE_HK_TEMP_FPA1 (raw)	PE HK FPA temperature 1
ECSN0314: PE_HK_TEMP_FPA2 (raw)	PE HK FPA temperature 2
ECSN0315: PE_HK_TEMP_PE (raw)	PE HK PE temperature
ECSN0316: PE_HK_33V (raw)	PE HK measure of 3.3 voltage
ECSN0317: PE_HK_7V5_LOSS_FLAG	7V5_LOSS_FLAG related to loss of 7.5 V supply (used in the PE for analog supply and detector supply)
ECSN0319: PE_HK_VDET_DIG_OVC	Overcurrent flag 1
ECSN0320: PE_HK_VDET_ANA_OVC	Overcurrent flag 2
ECSN0321: PE_ROIC_REQ	PE ROIC frequency
ECSN0322: TSCP_ACTUAL_POS	Current telescope position
ECSN0323: TSCP_TARGET_POS	Last requested telescope position
ECSN0324: TSCP_ROT_STAT	Rotation status (0: not rotating, 1: not rotating zero 1, 2: not rotating zero 2, 3: rotating to home 1, 4: rotating to home 2, 5:

Parameter	Description
	rotating slow, 6: rotating fast, 99: stopped on emergency).
ECSN0325: TSCP_ROT_SLOW_2_ACTIVE	Slow sensor 2 is active
ECSN0326: TSCP_ROT_SLOW_1_ACTIVE	Slow sensor 1 is active
ECSN0327: TSCP_ROT_ZERO_2_ACTIVE	Zero sensor 2 is active
ECSN0328: TSCP_ROT_ZERO_1_ACTIVE	Zero sensor 1 is active
ECSN0329: FPGA_ROT_BRIDGE_2_HI_CUR	Bridge 2 high current rise warning
ECSN0330: FPGA_ROT_BRIDGE_1_HI_CUR	Bridge 1 high current rise warning
ECSN0331: FPGA_ROT_BRIDGE_2_OVRDRV	Bridge 2 overdrive error
ECSN0332: FPGA_ROT_BRIDGE_1_OVRDRV	Bridge 1 overdrive error
ECSN0333: FPGA_ROT_STAT_DIRECTION	Rotation Direction
ECSN0334: FPGA_ROT_STAT_RUNNING	Rotating
ECSN0335: FPGA_ENDSW_STAT	Content of the FPGA's end switch status register
ECSN0336: FPGA_MOT_SPEED	Content of the FPGA's motor speed registers (0x2c, 0x2d)

Table 6: Information contained in housekeeping packet frame type 3 (PE and rotation status information).

Parameter	Description
PUS_TIME_UTC	Packet Utilization Standard time (UTC)
PUS_TIME	Packet Utilization Standard Time (Spacecraft clock time)
ECSN1601: TM_IDENTIFIER_16	Value used to define a housekeeping packet
ECSN1602: TM_DISCRIMINATOR_16	Value defining housekeeping packet frame type
ECSN1603: TM_TIME_PREAMBLE_16	Redundant value used to pad time value
ECSN1604: TM_TIME_COARSE_16	Time of window acquisition to second precision
ECSN1605: TM_TIME_FINE_16	Time of window acquisition to millisecond precision
ECSN1606: TM_TIME_16	CaSSIS clock timestamp of window acquisition
ECSN1607: FSW_VERSION	Firmware version
ECSN1609: FSW_MODE	Current FSW mode (0x0F: safe mode, 0xF0: normal mode)
ECSN1610: IMEM_USED	Number of used image memory slots
ECSN1611: IMEM_FREE	Available free image memory slots
ECSN1612: IMEM_COMP	Number of compressed slots
ECSN1613: IMEM_COMPRESS_FREE	Number of free slots for compressed image data.
ECSN1614: IMEM_STATE	Memory usage state.
ECSN1615: SC_LSENT_ITAG_UID	The unique id of the corresponding prepare image TC
ECSN1616: SC_LSENT_ITAG_WIN_CNT	PE window counter

Parameter	Description
ECSN1617: SC_LSENT_ITAG_SEQ_CNT	Exposure counter
ECSN1618: SC_LCOMP_ITAG_UID	The unique id of the corresponding prepare image TC
ECSN1619: SC_LCOMP_ITAG_WIN_CNT	PE window counter
ECSN1620: SC_LCOMP_ITAG_SEQ_CNT	Exposure counter
ECSN1621: FSW_UPTIME_HIGH	FSW up time since last boot in 100 usec
ECSN1622: FSW_UPTIME_LOW	FSW up time since last boot in 100 usec
ECSN1624: REC_1_POWER_DOWN_ERR	= 1 if last power down was in normal mode.
ECSN1625: REC_1_PSTORE_INVALID	Integrity validation of the persistent store failed.
ECSN1626: REC_1_PSTORE_EDAC_ERR	Uncorrectable edac error was detected by the bootloader during last boot at the persistent storage area.
ECSN1627: REC_1_IMAGE1_EDAC_ERR	Uncorrectable edac error was detected by bootloader during last boot at the custom image area.
ECSN1628: REC_1_BOOTDESC_EDAC_ERR	Uncorrectable edac error was detected by bootloader during last boot at the boot descriptor area.
ECSN1629: REC_1_INT_CLOCK_ERR	Internal clock sync error.
ECSN1630: REC_1_MIL_ADDRESS_ERR	MIL_ADDR_PARITY_ERROR=1 -> fallback RT addr is used.
ECSN1631: FPGA_UPTIME	FPGA uptime in seconds

Table 7: Information contained in housekeeping packet frame type 16 (FSW status 1 information).

Parameter	Description
PUS_TIME_UTC	Packet Utilization Standard time (UTC)
PUS_TIME	Packet Utilization Standard Time (Spacecraft clock time)
ECSN1701: TM_IDENTIFIER_17	Value used to define a housekeeping packet
ECSN1702: TM_DISCRIMINATOR_17	Value defining housekeeping packet frame type
ECSN1703: TM_TIME_PREAMBLE_17	Redundant value used to pad time value
ECSN1704: TM_TIME_COARSE_17	Time of window acquisition to second precision
ECSN1705: TM_TIME_FINE_17	Time of window acquisition to millisecond precision
ECSN1706: TM_TIME_17	CaSSIS clock timestamp of window acquisition
ECSN1707: FSW_LAST_ISSUE	Last issued command unique id
ECSN1708: FSW_LAST_EXEC	Last executed command unique id
ECSN1709: FSW_LAST_RCV	Last received command unique id
ECSN1710: FSW_LAST_FAILED	Last failed command unique id
ECSN1711: FSW_LAST_ECODE	Last error code of command processing.

Parameter	Description
ECSN1712: FSW_CMEM_FREE	Number of available command slots
ECSN1713: FSW_0_IMGMAN_FAILURE	Fatal error bit
ECSN1714: FSW_0_IMGMAN_STATUS_PE	PE status
ECSN1715: FSW_0_IMGMAN_STATUS	Internal status of image manager
ECSN1716: FSW_0_IMGMAN_LAST_ERROR	Last error of image manager
ECSN1717: FSW_0_ROTMAN_FAILURE	Fatal error bit
ECSN1718: FSW_0_ROTMAN_STAT_MOTOR	Motor rotation status
ECSN1719: FSW_0_ROTMAN_STAT	Internal status of rotation manager
ECSN1720: FSW_0_ROTMAN_LAST_ERROR	Last error of rotation manager
ECSN1721: FSW_0_COMPMAN_STATUS	Status of compression manager
ECSN1722: FSW_0_COMPMAN_LAST_ERROR	Last error of compression manager
ECSN1723: FSW_0_SCIMAN_STATUS	Status of science data manager
ECSN1724: FSW_0_SCIMAN_LAST_ERROR	Last error of science data manager
ECSN1725: LMTIME_F_CORR	Time sync counter for forward correction
ECSN1726: LMTIME_B_CORR	Time sync counter for backward correction
ECSN1728: LMTIME_LAST_DIFF	The last difference of the local and mil time
ECSN1729: CMD_REC_CNT	Number of received commands since last boot
ECSN1730: CMD_EXEC_CNT	Number of executed commands since last boot
ECSN1731: CMD_FAIL_CNT	Number of failed commands since last boot
ECSN1732: CMD_CRC_ERR_CNT	Number of errors in TCs since last boot

Table 8: Information contained in housekeeping packet frame type 17 (FSW status 2 information).

Parameter	Description
PUS_TIME_UTC	Packet Utilization Standard time (UTC)
PUS_TIME	Packet Utilization Standard Time (Spacecraft clock time)
ECSN1801: TM_IDENTIFIER_18	Value used to define a housekeeping packet
ECSN1802: TM_DISCRIMINATOR_18	Value defining housekeeping packet frame type
ECSN1803: TM_TIME_PREAMBLE_18	Redundant value used to pad time value
ECSN1804: TM_TIME_COARSE_18	Time of window acquisition to second precision
ECSN1805: TM_TIME_FINE_18	Time of window acquisition to millisecond precision
ECSN1806: TM_TIME_18	CaSSIS clock timestamp of window acquisition
ECSN1807: MISSING_UPD_FRM_CNT	Number of missing frames during current update process
ECSN1808: MISSING_UPD_FRM_SEQ_CNT	Current missing frame's sequence counter

Parameter	Description
ECSN1809: ONGOING_UPD_UID	The unique ID in the TCs of the update session in progress.
ECSN1810: BOOTUP_CNT	Number of boot ups
ECSN1811: MRAM1_EDAC_ERR_CNT	Correctable error counter in MRAM1 since last boot.
ECSN1813: SDRAM_EDAC_ERR_CNT	Correctable error counter in SDRAM since last boot.
ECSN1815: MRAM1_EDAC_UNCORR_CNT	MRAM1 uncorrectable error during last boot
ECSN1816: MRAM1_HEALTH	MRAM1 health status reported by bootloader. 0xc0: entire MRAM1 was cleared, 0x30: persistent storage was recovered (cleared), 0x0c: image1 was recovered (cleared), 0x03: first 32 bytes of the boot descriptor was recovered, 0x00: mram1 good.
ECSN1817: STAT_1_MILMAN_STATUS	Status of process manager
ECSN1818: STAT_1_MILMAN_LASTERROR	Last error of process manager
ECSN1819: STAT_1_TIMESRV_STATUS	Status of time server
ECSN1820: STAT_1_TIMESRV_LASTERROR	Last error of timer server
ECSN1821: STAT_1_HKMAN_STATUS	Status of housekeeping manager
ECSN1822: STAT_1_HKMAN_LASTERROR	Last error of housekeeping manager
ECSN1823: STAT_1_THMAN_STATUS	Status of thermal manager
ECSN1824: STAT_1_THMAN_LASTERROR	Last error of thermal manager
ECSN1825: UPDATE_REC_CNT	Number of received update TCs in current update session.
ECSN1826: BOOT_FROM	Source of running FSW image. 0x00: MRAM0, 0xFF: MRAM1.

Table 9: Information contained in housekeeping packet frame type 18 (FSW status 3 information).