CASSIS EXPERIMENT TO ARCHIVE INTERFACE CONTROL DOCUMENT

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List of 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

Scope of the 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. 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. This document includes descriptions of archive products that are produced by the CaSSIS team.

The contents of this document is as follows: Section 1 gives a description of the CaSSIS mission goals and an overview of the operation of the instrument. Section 2 describes the data that is generated by the instrument and during the calibration procedure. Section 3 describes how this data is validated. Section 4 gives how the data is stored and Section 5 the format of the data that is stored. Finally, Section 6 describes how the data is archived and what is delivered to the PSA.

1 CaSSIS EXPERIMENT GENERAL DESCRIPTION

1.1 Mission and Instrument Overview

The ESA ExoMars program consist of two stages: an orbiter (called Trace Gas Orbiter, TGO) launched in 2016 and a rover to be launched in 2020. 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, 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 and investigates dynamic surface processes and certify potential future landing sites. CaSSIS observes a 9 km wide swath thereby providing the best colour imaging acquired from Mars, so far.

CaSSIS comprises two major units: 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 and mount the CRU to the spacecraft. The ELU contains the boards with the electronics required to operate the camera.

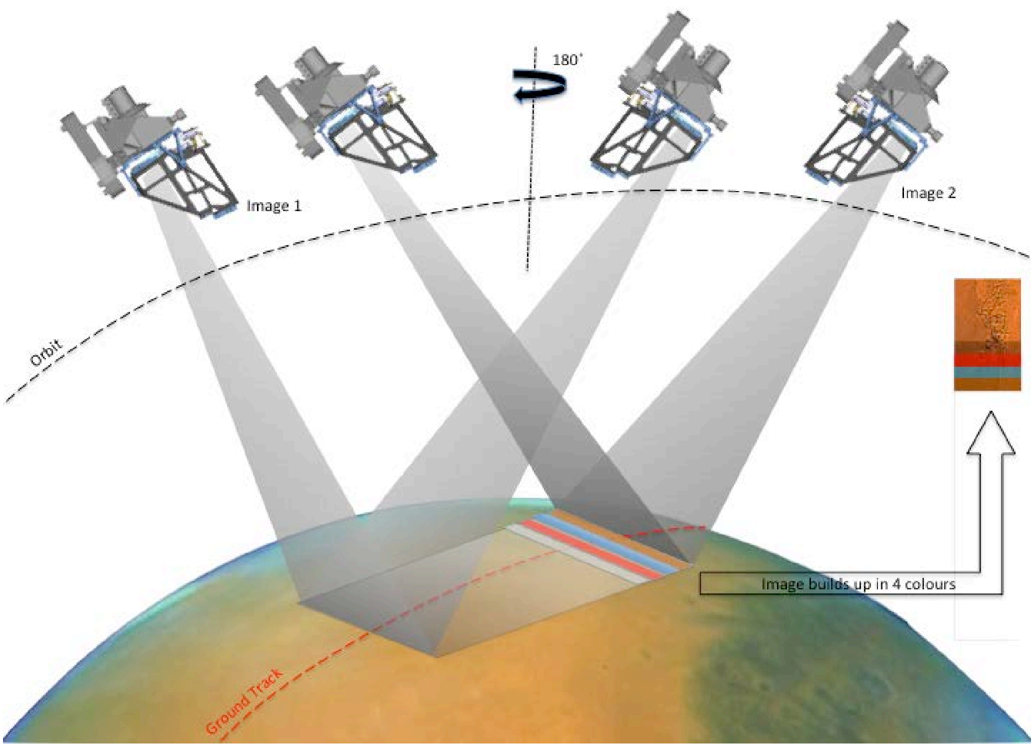


Figure 1: CaSSIS Stereo Image Acquisition

1.2 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 compile and prioritize a list of observation targets needed to test specific hypotheses concerning active surface processes on Mars. We begin to address this objective early in the mission, prior to new trace-gas discoveries from the TGO. 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). Once these discoveries are made (if that goal is realized), CaSSIS will place 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 new candidate 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 has recently been approved for priority Mars Reconnaissance Orbiter (MRO) coverage as a candidate landing site for the Mars Science Laboratory; this site is at the margin of the Syrtis Major methane plume identified by Mumma et al. (2009). It is likely that the pair of NASA/ESA landers in 2020 will also consider methane areas for landing sites. At the workshop ‘Habitability and Landing Sites’ held in the UK (Cockell et al., 2009) the surfaces associated with methane plumes were identified as high priority exploration targets. However, the best locations will presumably be found by TGO, and MRO/HiRISE may or may not be able to certify new landing sites post 2017. CaSSIS cannot identify meter-scale hazards, but it can provide the 5 m scale slope information needed to complete certification of thousands of locations imaged by HiRISE, but not in stereo.

1.3 Experiment Overview

Whilst the goals and objectives of TGO are rather straightforward, the spacecraft design proposed by ESA does present some difficulties for remote-sensing. The spacecraft is generally nadir-pointing but it 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 however varies 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 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 is 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 is required to employ a quasi-push broom mode, also called push-frame. The detector is a hybrid CMOS Active Pixel Sensor (APS) 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 S/C 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).

1.4 Instrument Description

A full description of CaSSIS can be found in Thomas et al. (2017) /RD-13/.

CaSSIS is based around an 875 mm focal length carbon-fibre reinforced polymer (CFRP) telescope with a 135 mm primary mirror and a 2k x 2k 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 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. The diagram shows how this is combined with the stereo acquisition. 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 allows us to build up a continuous swath in each of the four colours.

The FSA is mounted directly above the detector providing images in 4 wavelength bands. Two of these (480.5nm and 676.5nm prior to convolution with the rest of the instrument) correspond closely to bands used by the HiRISE instrument on the Mars Reconnaissance Orbiter. Two other filters split the NIR wavelengths with centres at 838 nm and close to 985 nm. Analyses show that the filters provide good differentiation between expected surface minerals, particularly Fe-bearing phases.

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 shots.

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. Coverage will be of ~3% of the Martian surface per Mars year.

1.5 Experiment Operating Modes Description

The operational modes are described in the Experiment Operations Plan (EXM-CA-PLN-UBE-00024), [RD05]. A typical parameter table for image acquisition is shown in Table 1.

Table 1 Typical command parameters to control swath width, length, windowing and binning

Parameter	Value	Description
T_exp	1.5 ms	Exposure time
Num_exp	40	Number of exposures
Step_exp	400 ms	Time between each exposure
RIOC_Freq	5 MHz	RIOC clock frequency
Num_win	4	Number of exposure windows (4 includes each filter)
Bin_win1	0	Binning factor of window 1
Bin_win2	0	Binning factor of window 2
Bin_win3	0	Binning factor of window 3
Bin_win4	1	Binning factor of window 4
Bin_win5	0 (ignored)	N/A
Bin_win6	0 (ignored)	N/A
Win1_str	(0,300)	Start of window 1 in pixels on detector
Win1_end	(2047,549)	End of window 1 in pixels on detector
Win2_str	(0,600)	Start of window 2 in pixels on detector

Parameter	Value	Description
Win2_end	(2047,849)	End of window 2 in pixels on detector
Win3_str	(0,900)	Start of window 3 in pixels on detector
Win3_end	(2047,1149)	End of window 3 in pixels on detector
Win4_str	(0,1200)	Start of window 4 in pixels on detector
Win4_end	(2047,1449)	End of window 4 in pixels on detector
Win5_str	Ignored	N/A
Win5_end	Ignored	N/A
Win6_str	Ignored	N/A
Win6_end	Ignored	N/A
PE_test	0	Proximity electronics test flag
Win1_CompR	0	Compression factor for window 1
Win2_CompR	0	Compression factor for window 2
Win3_CompR	0	Compression factor for window 3
Win4_CompR	0	Compression factor for window 4
Win5_CompR	Ignored	N/A
Win6_CompR	Ignored	N/A

Command files typically result in a 9.5 km x ~30 km footprint on the ground for the total image with each framelet being 9.5 km x 1.3 km. Each framelet produces a 1.05 Mbyte image in raw form which will be expanded to a 4 byte integer on ground (i.e. 2.10 MB per framelet). Onboard compression has been implemented so 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).

1.6 Calibration

1.6.1 On-ground Calibration

The CaSSIS On-ground calibration is described in the CaSSIS Calibration Programme (EXM-CA-PLN-UBE-10000) [RD06] and the Calibration Report [RD07]. It should be noted that the Calibration Report is planned to be archived toward the end of 2019.

1.6.2 In-flight Calibration

The CaSSIS in-flight calibration is described in the Experiment Operations Plan (EXM-CA-PLN-UBE-00024), [RD05], section 9.

2 DATA GENERATION PROCESS

The CaSSIS science products are produced by the CaSSIS Instrument Team. This section describes how data is generated by CaSSIS and the stages this data goes through during the calibration procedure. In Section 2.1 and 2.2, image definitions are given and an overview of how CaSSIS data is acquired is given respectively. Section 2.3 describes an overview of how the software related to CaSSIS is developed and managed. Finally, Section 2.4 describes in detail the different data levels that are generated by the CaSSIS data calibration process.

2.1 Definitions

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

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

2.2 Scientific Measurements

CaSSIS produces 2D images of the surface of Mars with associated header information. CaSSIS operates in a push-frame mode and is a targeted instrument – it only acquires specific targets on the surface. Typically, there are two targets per orbit where only one is acquired using the instrument rotation to produce the data needed to generate stereo.

Each target is acquired in the following way. A parameter table in the instrument is set by telecommand (an example parameter table was given in Table 1). The parameter table controls the swath width, swath length, binning and filters 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.

Each exposure results in the production of 1 to 6 framelets (sub-exposures). Each framelet is transmitted to ground with its own header information. Typically, framelets are 2048 x 256 in size. The detector is covered with 4 filters (PAN, BLU, RED, NIR) and usually framelets are taken from the positions corresponding to these filters. The timing of the acquisition of the exposures in the exposure sequence are such that there is overlap between the framelets on the ground-track. Hence, by correlation and matching, a complete image along-track in one colour can be produced on ground after processing.

In the case of the stereo pair, two images of the same target are generated, separated in time by approximately 47 seconds but with different viewing geometries – that geometry change being generated by the spacecraft motion and the rotation of the CaSSIS instrument. The fundamental acquisition method is however identical.

The current version of the CaSSIS flight software (v1.03) was found to become increasingly unstable for continuous CaSSIS operations greater than 24hrs. A reboot of CaSSIS is therefore performed once roughly every 24hrs to minimize this issue. The imaging routine of CaSSIS was adjusted to mirror these reboots, such that an imaging period during an STP is split into ‘reboot periods’, where a reboot period refers to a rough 24hr observing period between reboots during an STP. The effect of these reboot periods mainly affects how the data is stored by the CaSSIS team, with data storage being split into these reboot periods. This is discussed further in Section 4.

2.3 CaSSIS Software Overview

An overview of all software aspects related to CaSSIS is shown in Figure 2. The software shown is applicable to everything from the flight software, to the downlink and calibration software. Each aspect of the software described in Figure 2 includes what the software is for, an acronym for where the software is developed and which institution is responsible for the development of that specific software. Furthermore, the individuals responsible for managing the main components of the software described in Figure 2 are shown in Figure 3.

All downlink and uplink software routines shown in Figure 3 are under git configuration control for management consistency.

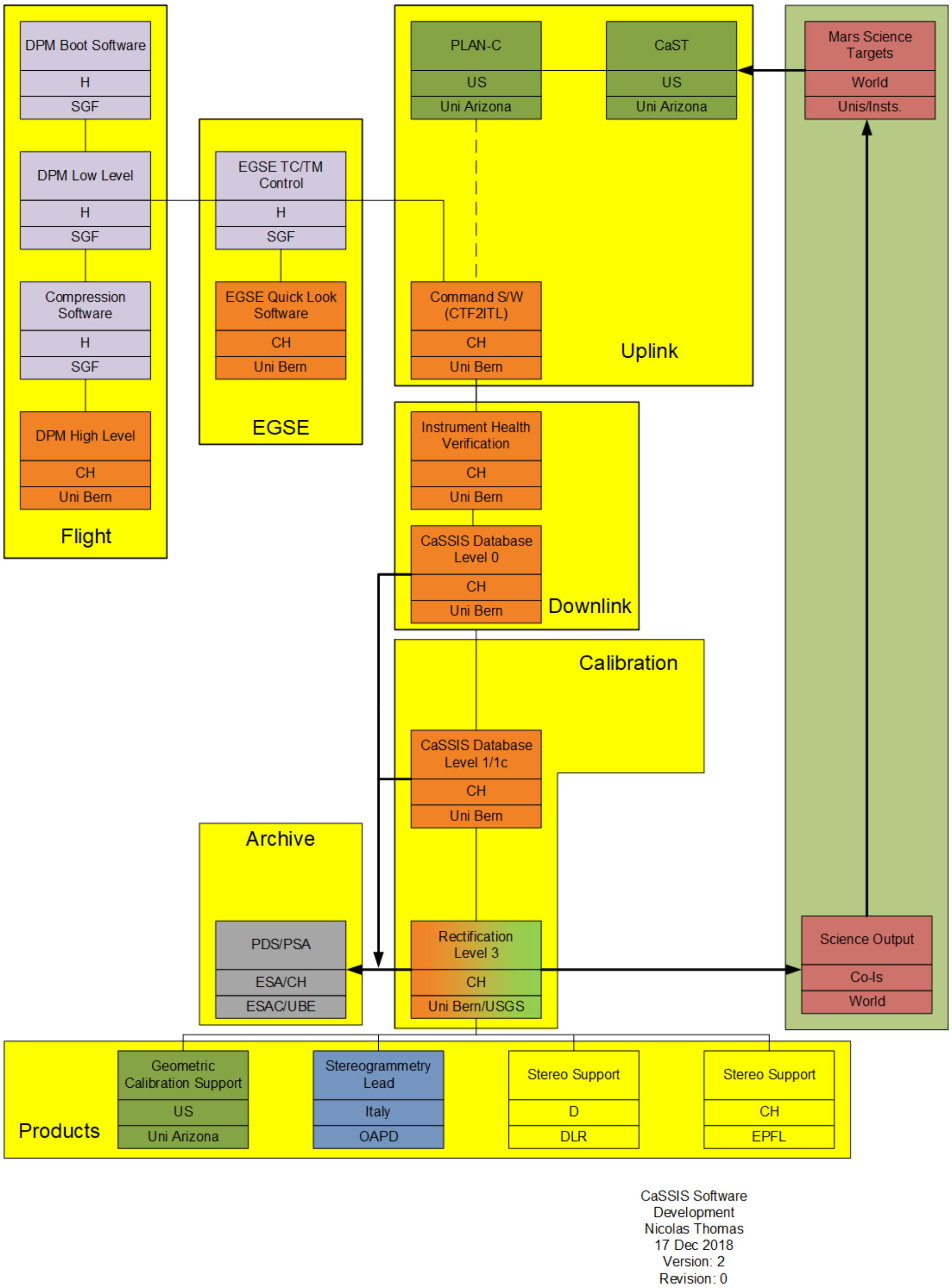


Figure 2: Software overview for all aspects of CaSSIS.

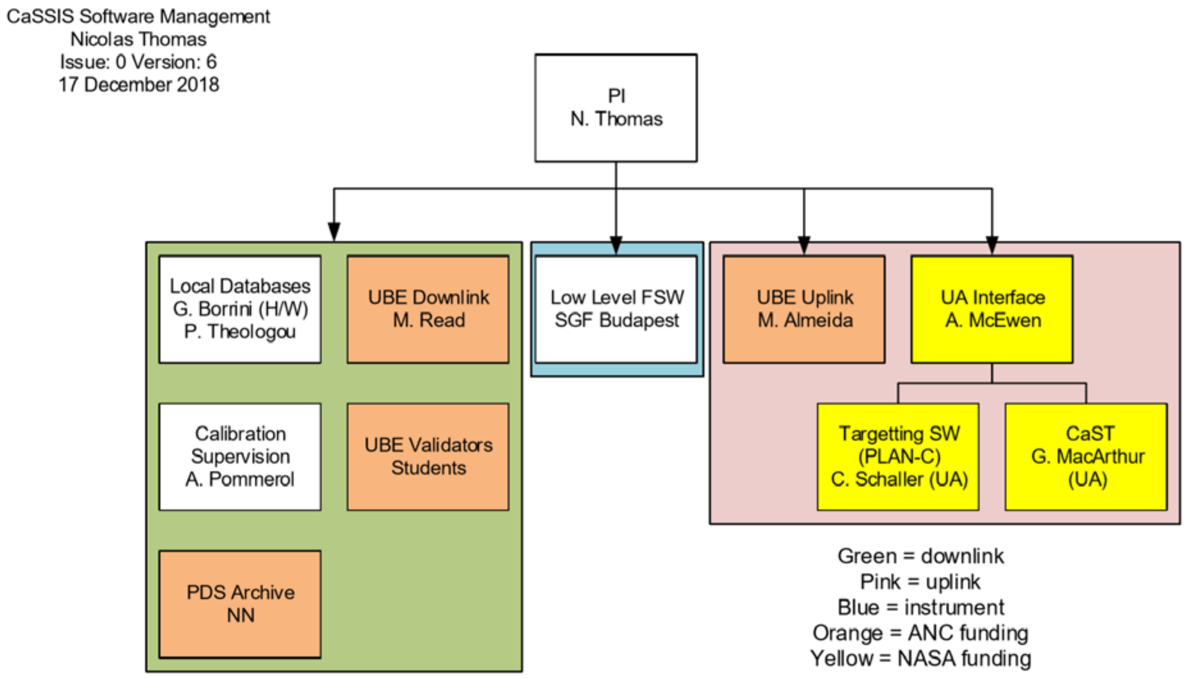


Figure 3 Software management and control

2.4 Data Generation Summary

The following section describes what/how products are produced during the CaSSIS data reduction process. An overview of this data reduction process is shown in Figure 4, with the data that is output from each step of this process being described in the following text. Specific details of exactly what files are generated during this process are discussed further in Section 4. A summary of the data generated according to PDS type nomenclature (raw, partially processed, calibrated etc.) is given in Table 2.

A detailed description of the calibrations/data extraction procedures can be found in the 'CaSSIS Calibration Report' document that will be archived with this document. For the purposes of this document, calibration procedures are summarized without going into specific detail. A detailed description of the calibration steps can be found in the CaSSIS Calibration Report which, as noted in Section 1.6.1, is planned to be archived toward the end of 2019.

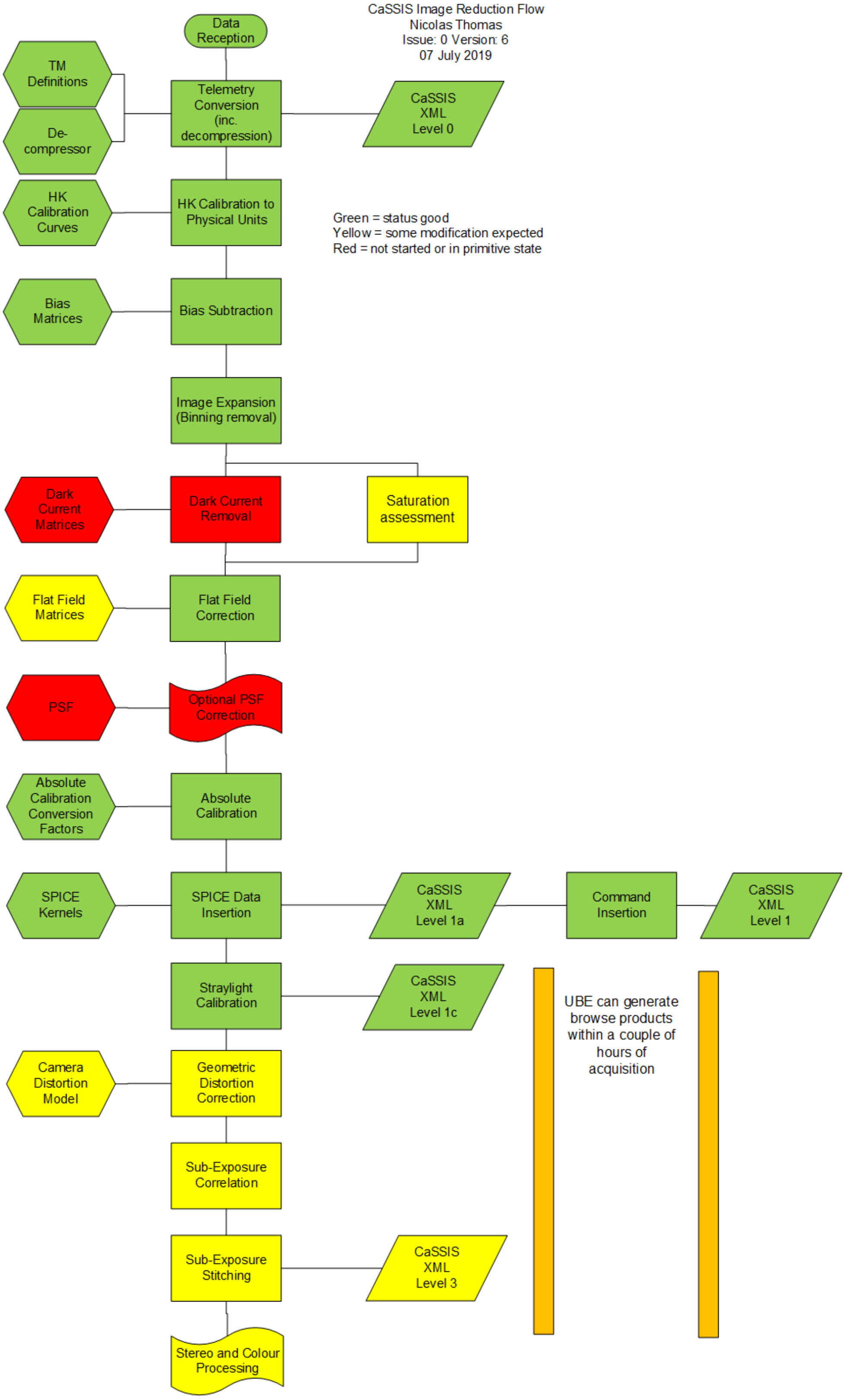


Figure 4 Data reduction flow overview

Table 2: PDS to University of Bern nomenclature

PDS nomenclature	Bern Products equivalent	Comments
Raw (Level0)	Level0	Refers to raw science data, housekeeping telemetry and telecommand telemetry
Partially Processed	Level1a, level1	Refers to raw science data that has some, but not complete set of calibrations applied
Calibrated (Level1)	Level1c, stitched	Refers to raw science data where all calibrations have been applied. Level1c data refers to calibrated framelets, whereas stitched refers to level1c framelets that have been stitched together
Geometry (Level3)	Level3	Refers to level1c framelets that have been geometrically corrected and stitched together
Derived	N/A	Derived products not available at this time

2.4.1 Housekeeping telemetry (Raw telemetry) generation

Housekeeping telemetry data is received from the EDDS as a data file, which contains a concatenation of 1553 HK packets with APID=339 and 340. These packets are converted into an XML format and from this into IDL structures which can be analyzed. The housekeeping telemetry data is generated using an IDL pipeline based around routines that are already available. They are shown in Table 3. It should be noted that identical routines are used for other levels of data generation. As such, each IDL routine used in the entire data generation pipeline is only described once upon first use in the pipeline below. Housekeeping telemetry data is output as IDL structure files. Specific housekeeping variables (voltages, currents, temperatures etc.) are also graphically output for validation purposes (discussed in Section 3.1).

Each IDL structure file contains a different 'frame type' of housekeeping telemetry. CaSSIS has a total of 7 used housekeeping frame types (see CaSSIS flight software manual EXM-CA-UMA-UBE-10001). Each frame (and therefore associated IDL structure file) represents a collection of housekeeping quantities. Frame 1 contains CaSSIS temperature information extracted from the housekeeping telemetry, frame 2 CaSSIS zone temperatures, frame 3 voltages and currents, frame 4 proximity electronics housekeeping and rotation status, frame 5 FSW status, frame 6 FSW status 2 and frame 7 FSW status 3. Each frame has an associated hexid of 0x00, 0x01, 0x02, 0x03, 0x10, 0x11, 0x12 respectively. The IDL structure files generated for each of these frame types uses the associated integer of the hexid frame value in the filename. Tables 4 – 10 give the contents of housekeeping packets for each of the respective frame types. Frame types in each respective table are referred to using the integer value of the associated hexid of the frame type (0, 1, 2, 3, 16, 17, 18 resepectively).

Table 3: IDL routines used to generate IDL structures of 1553 HK packets.

HK TM Conversion Routines				
Procedure/function name	**Version**	**Description**	**Author**	**Call**
c_top_batch_hk_extract	V1.04	To make a batch conversion of 1553 HK packets into directory structure	NT	c_top_batch_hk_extract,top_directory,mission_phase=mission_phase,status,help=help,sub_dir_filter=sub_dir_filter,debug=debug,plot_zero=plot_zero,delete=delete,version_info=version_info,verbose=verbose,no_xml=no_xml

c_batch_hk_extract_all	V1.07	To get APID 339 and 340 1553 HK packets out of EDDS format to individual files	NT	c_batch_hk_extract_all,filename,out_root=out_root,status,debug=debug,mission_phase=mission_phase,remove_duplicates=remove_duplicates,HELP=HELP,combine=combine,report_file=report_file,plot_zero=plot_zero,verbose=verbose,no_xml=no_xml
c_read_hk_tm_table	V2.1	To read the HK telemetry definition table	NT	c_read_hk_tm_table,hk_tm_table [,status,hk_tm_table_numbers=hk_tm_table_numbers,size_hk_frames,status,filename=filename,help=help]
c_read_hk_frame	V1.1	To read an HK frame from a file into an IDL byte array	NT	c_read_hk_frame, filename,hk_frame [, status, HELP=HELP]
c_hk_dissolve	V1.02	To extract CaSSIS HK frames from EDDS batch request	NT	c_hk_dissolve,hk_tm_frame,cassis_frames [,HELP=HELP,/brute_force,/verbose]
c_remove_blank_1553_hk_packets	V1.01	To remove blank 1553 HK packets	NT	cassis_frames_out=c_remove_blank_1553_hk_packets(cassis_frames_in [,status1, /help])
c_timecode_to_time	V1.3	To convert CaSSIS packet timecode into seconds	NT	time_out=c_timecode_to_time(CaSSIS_code [,status,HELP=HELP, /HEXADECIMAL,TIMECODE_STRING=TIMECODE_STRING])
c_hk_tm_frame_to_components	V1.1	To extract the data from the HK frame	NT	c_hk_tm_frame_to_components,hk_tm_frame,hk_tm_table_numbers,cassis_frame,cassis_hk_frame_type,frame_attributes,frame_attribute_values
c_hk_to_xml	V1.0	To write a CaSSIS HK file to an XML header	NT	c_hk_to_xml,frame_attributes,frame_attribute_values,oCaSSIS,status,HELP=HELP
c_new_child	V2.0	Add new section to CaSSIS header	NT	c_new_child(oInput, block_name, attributes, attribute_values [, status,HELP=HELP])

c_makefilename	V1.5	Produce a filename for CaSSIS datafiles	NT	filename=c_makefilename(mission_phase,start_time,filter,sub_exposure_number,process_level [, status ,addendum=addendum, isis_id=isis_id, HELP=HELP])
c_update_history	V2.2	Update modification history of CaSSIS header	NT	oOutput=c_update_history(oINPUT,process,routine,routine_version [,status,version_date=version_date,help=help])
c_write_image	V2.3	Write data to data and xml file	NT	c_write_image,filename,oheader,image [,status,help=help, directory=directory, description = description, value_offset=value_offset,unit=unit,scaling_factor=scaling_factor]
c_remove_duplicate_hk_files	V2.0	To remove any duplicate HK packets	NT	c_remove_duplicate_hk_files,in_directory [,status,HELP=HELP,version_info=version_info]
c_combine_same_hk_frame_types	V1.4	Combine data from a HK frame into a single array	NT	c_combine_same_hk_frame_types,in_directory [,out_directory,frame_type=frame_type,all=all,values=values,out_root=out_root,status1,HELP=HELP,/no_write,report_array=report_array,time_stamp_array=time_stamp_array,plot_zero=plot_zero,version_info=version_info]
c_extract_hk_from_dump	V1.0	Extract all the HK frames from a dump file	NT	c_extract_hk_from_dump,filename,structure,status,HELP=HELP

Table 4: 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)
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)	PT1000 DPM Board (ADC value)
ECSN0008: PT_PE_2 (raw)	PT1000 on PE (No. 2) (ADC value)
ECSN0009: PT_PE_1 (raw)	PT1000 on PE (No. 1) (ADC value)
ECSN0010: PT_FPA_1 (raw)	PT1000 FPA (No. 1) (ADC value)
ECSN0011: PT_FPA_2 (raw)	PT1000 FPA (No. 2) (ADC value)
ECSN0012: PT_TEL_M1_1 (raw)	PT1000 Telescope Mirror 1 (No.1) (ADC value)
ECSN0013: PT_TEL_M1_2 (raw)	PT1000 Telescope Mirror 1 (No.2) (ADC value)

Parameter	Description
ECSN0014: PT_TEL_RB_1 (raw)	PT1000 Telescope Rear Baffle (No.1) (ADC value)
ECSN0015: PT_TEL_RB_2 (raw)	PT1000 Telescope Rear Baffle (No.2) (ADC value)
ECSN0016: PT_TEL_M2 (raw)	PT1000 Telescope Mirror 2 (ADC value)
ECSN0017: PT_TEL_FB (raw)	PT1000 Telescope Front Baffle (ADC value)
ECSN0018: PT_PCM_5V (raw)	PT1000 PCM Board near 5V DC/DC (ADC value)
ECSN0019: PT_PCM_PE (raw)	PT1000 PCM Board near PE DC/DC (ADC value)
ECSN0020: PT_RCM (raw)	PT1000 RCM Board (ADC value)
ECSN0021: PT_PCM_MOT (raw)	PT1000 PCM Board near Motor DC/DC (ADC value)
ECSN0022: PT_MOT_1 (raw)	PT1000 Step Motor No. 1 (ADC value)
ECSN0023: PT_MOT_2 (raw)	PT1000 Step Motor No. 2 (ADC value)
ECSN0024: TSENS_H_STAT_01	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0025: TSENS_H_STAT_02	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0026: TSENS_H_STAT_03	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0027: TSENS_H_STAT_04	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)

Parameter	Description
ECSN0028: TSENS_H_STAT_05	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0029: TSENS_H_STAT_06	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0030: TSENS_H_STAT_07	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0031: TSENS_H_STAT_08	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0032: TSENS_H_STAT_09	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0033: TSENS_H_STAT_10	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0034: TSENS_H_STAT_11	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0035: TSENS_H_STAT_12	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0036: TSENS_H_STAT_13	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0037: TSENS_H_STAT_14	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)

Parameter	Description
ECSN0038: TSENS_H_STAT_15	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0039: TSENS_H_STAT_16	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0040: TSENS_H_STAT_17	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0041: TSENS_H_STAT_18	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0042: TSENS_H_STAT_19	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0043: TSENS_H_STAT_20	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0044: TSENS_H_STAT_21	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0045: TSENS_H_STAT_22	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0046: TSENS_H_STAT_23	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0047: TSENS_H_STAT_24	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)

Parameter	Description
ECSN0048: TSENS_H_STAT_25	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0049: TSENS_H_STAT_26	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0050: TSENS_H_STAT_27	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0051: TSENS_H_STAT_28	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0052: TSENS_H_STAT_29	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0053: TSENS_H_STAT_30	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0054: TSENS_H_STAT_31	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0055: TSENS_H_STAT_32	Temperature sensors health status. The 32 bit word contains the health status bit for every temperature sensor. 0: sensor failed, 1: sensor OK. (TBD)
ECSN0056: HEATER_H_STAT_FSW_01	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0057: HEATER_H_STAT_FSW_02	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)

Parameter	Description
ECSN0058: HEATER_H_STAT_FSW_03	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0059: HEATER_H_STAT_FSW_04	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0060: HEATER_H_STAT_FSW_05	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0061: HEATER_H_STAT_FSW_06	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0062: HEATER_H_STAT_FSW_07	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0063: HEATER_H_STAT_FSW_08	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0064: HEATER_H_STAT_FSW_09	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0065: HEATER_H_STAT_FSW_10	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0066: HEATER_H_STAT_FSW_11	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0067: HEATER_H_STAT_FSW_12	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)

Parameter	Description
ECSN0068: HEATER_H_STAT_FSW_13	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0069: HEATER_H_STAT_FSW_14	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0070: HEATER_H_STAT_FSW_15	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0071: HEATER_H_STAT_FSW_16	Heater health status. The 16 bit word contains the health status bit for each heather. 0: heater failed, 1: heater OK. (TBD)
ECSN0072: PE_RED_SENSOR	PE Redundant Heater Sensor Status
ECSN0073: PE_MAIN_SENSOR	PE Main Heater Sensor Status
ECSN0074: PE_RED_RUN	PE Redundant Heater Running
ECSN0075: PE_MAIN_RUN	PE Main Heater Running
ECSN0076: FPA_RED_SENSOR	FPA Redundant Heater Sensor Status
ECSN0077: FPA_MAIN_SENSOR	FPA Main Heater Sensor Status
ECSN0078: FPA_RED_RUN	FPA Redundant Heater Running
ECSN0079: FPA_MAIN_RUN	FPA Main Heater Running
ECSN0080: M1_RED_SENSOR	RB Redundant Mirror Sensor Status
ECSN0081: M1_MAIN_SENSOR	RB Main Heater Mirror Sensor Status

Parameter	Description
ECSN0082: RB_RED_SENSOR	RB Redundant Heater Sensor Status
ECSN0083: RB_MAIN_SENSOR	RB Main Heater Sensor Status
ECSN0084: RB_RED_RUN	RB Redundant Heater Running
ECSN0085: RB_MAIN_RUN	RB Main Heater Running
ECSN0086: M2_RED_SENSOR	FB Redundant Mirror Sensor Status
ECSN0087: M2_MAIN_SENSOR	FB Main Heater Mirror Sensor Status
ECSN0088: FB_RED_SENSOR	FB Redundant Heater Sensor Status
ECSN0089: FB_MAIN_SENSOR	FB Main Heater Sensor Status
ECSN0090: FB_RED_RUN	FB Redundant Heater Running
ECSN0091: FB_MAIN_RUN	FB 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
ECSN0096: PWR_STAT_OP	Operational Power On
ECSN0097: PWR_STAT_RED	Redundant Power On

Parameter	Description
ECSN0098: PWR_STAT_NOM	Nominal Power On

Table 5: 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)
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 (PE) temperature (ADC value)
ECSN0108: Z2_CALC_TEMP (raw)	Zone 2 (FPA) temperature (ADC value)
ECSN0109: Z3_CALC_TEMP (raw)	Zone 3 (mirror 1) temperature (ADC value)
ECSN0110: Z4_CALC_TEMP (raw)	Zone 4 (mirror 2) temperature (ADC value)

Parameter	Description
ECSN0111: Z5_CALC_TEMP (raw)	Zone 5 (RCM board) temperature (ADC value)
ECSN0112: Z1_MIN_TEMP (raw)	Zone 1 (PE) target temperature min (ADC value)
ECSN0113: Z2_MIN_TEMP (raw)	Zone 2 (FPA) target temperature min (ADC value)
ECSN0114: Z3_MIN_TEMP (raw)	Zone 3 (mirror 1) target temperature min (ADC value)
ECSN0115: Z4_MIN_TEMP (raw)	Zone 4 (mirror 2) target temperature min (ADC value)
ECSN0116: Z5_MIN_TEMP (raw)	Zone 5 (RCM board) target temperature min (ADC value)
ECSN0117: Z1_MAX_TEMP (raw)	Zone 1 (PE) target temperature max (ADC value)
ECSN0118: Z2_MAX_TEMP (raw)	Zone 2 (FPA) target temperature max (ADC value)
ECSN0119: Z3_MAX_TEMP (raw)	Zone 3 (mirror 1) target temperature max (ADC value)
ECSN0120: Z4_MAX_TEMP (raw)	Zone 4 (mirror 2) target temperature max (ADC value)
ECSN0121: Z5_MAX_TEMP (raw)	Zone 5 (RCM board) target temperature max (ADC value)
ECSN0122: Z31_CALC_TEMP (raw)	Zone 3 (rear baffle) temperature (ADC value)
ECSN0123: Z41_CALC_TEMP (raw)	Zone 4 (front baffle) temperature (ADC value)
ECSN0124: Z31_MIN_TEMP (raw)	Zone 3 (rear baffle) target temperature min (ADC value)
ECSN0125: Z41_MIN_TEMP (raw)	Zone 4 (front baffle) target temperature min (ADC value)
ECSN0126: Z31_MAX_TEMP (raw)	Zone 3 (rear baffle) target temperature max (ADC value)

Parameter	Description
ECSN0127: Z41_MAX_TEMP (raw)	Zone 4 (front baffle) target temperature max (ADC value)
ECSN0128: ZMOT_CALC_TEMP (raw)	Motor temperature (ADC value)

Table 6: 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)
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 for PT OpAmps (ADC value)
ECSN0208: I_3V3_DPM (raw)	Current on 3.3V DPM Supply (ADC value)
ECSN0209: U_3V3_DPM (raw)	3.3V of DPM (ADC value)

Parameter	Description
ECSN0210: I_1V8 (raw)	Current of 1.8V Processor Supply (ADC value)
ECSN0211: U_1V8 (raw)	1.8V Processor Core Voltage (ADC value)
ECSN0212: U_5V_OP (raw)	5V Operating Voltage (ADC value)
ECSN0213: U_5V_ANA (raw)	5V Analogue Voltage (ADC value)
ECSN0214: I_5V_ANA (raw)	Current of 5V Analogue Voltage (ADC value)
ECSN0215: I_3V3_FPGA (raw)	Current of 3.3V FPGA Voltage (ADC value)
ECSN0216: U_3V3_FPGA (raw)	3.3V FPGA Voltage (ADC value)
ECSN0217: I_1V2_FPGA (raw)	Current of 1.2V FPGA Voltage (ADC value)
ECSN0218: U_1V2_FPGA (raw)	1.2V FPGA Voltage (ADC value)
ECSN0219: U_24V_MOT_1 (raw)	24V Motor DC/DC No. 1 Voltage (ADC value)
ECSN0220: U_24V_MOT_2 (raw)	24V Motor DC/DC No. 2 Voltage (ADC value)
ECSN0221: U_3V3_PE (raw)	PE Digital 3.3V Voltage (ADC value)
ECSN0222: I_3V3_PE (raw)	PE Digital 3.3V Current (ADC value)
ECSN0223: U_8V5_PE (raw)	PE Detector Positive +8.5V Voltage (ADC value)
ECSN0224: I_8V5_PE (raw)	PE Detector Positive +8.5V Current (ADC value)
ECSN0225: U_N_8V5_PE (raw)	PE Detector Negative -8.5V Voltage (ADC value)

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

Table 7: 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)
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.

Parameter	Description
ECSN0309: PE_HK_DETECTOR_ON	Commanded detector status. 0: off, 1: on.
ECSN0310: PE_HK_LASTVENT	PE HK Last event (PE HK 30)
ECSN0311: PE_HK_ADDRRW	PE HK Address read/writen (PE HK 42 | PE HK 41)
ECSN0312: PE_HK_ADDRRW_CONT	PE HK Address read/writen content (PE HK 44 | PE HK 43)
ECSN0313: PE_HK_TEMP_FPA1 (raw)	PE HK FPA temperature 1 (PE HK 46 | PE HK 45)
ECSN0314: PE_HK_TEMP_FPA2 (raw)	PE HK FPA temperature 2 (PE HK 48 | PE HK 47)
ECSN0315: PE_HK_TEMP_PE (raw)	PE HK PE temperature (PE HK 50 | PE HK 49)
ECSN0316: PE_HK_33V (raw)	PE HK measure of 3.3 voltage (PE HK 56 | PE HK 55)
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	VDET_DIG_OVC related to overcurrent on VDET_DIG line
ECSN0320: PE_HK_VDET_ANA_OVC	VDET_ANA_OVC related to overcurrent on VDET_ANA line
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: rotating slow, 6: rotating fast, 99:

Parameter	Description
	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 8: Information contained in housekeeping packet frame type 16 (FSW status 1 information).

Parameter	Description

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

Parameter	Description
ECSN1616: SC_LSENT_ITAG_WIN_CNT	PE window counter
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	OBT and internal clock sync error.
ECSN1630: REC_1_MIL_ADDRESS_ERR	MIL_ADDR_PARITY_ERROR=1 -> fallback RT addr is used.

Parameter	Description
ECSN1631: FPGA_UPTIME	FPGA uptime in seconds

Table 9: 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)
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

Parameter	**Description**
ECSN1711: FSW_LAST_ECODE	Last error code of command processing. (TBD)
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

Parameter	Description
ECSN1728: LMTIME_LAST_DIFF	The last difference of the local and mil time (abs)
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 CRC errors in TCs since last boot

Table 10: Information contained in housekeeping packet frame type 18 (FSW status 3 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

Parameter	Description
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
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 EDAC error counter in MRAM1 since last boot.
ECSN1813: SDRAM_EDAC_ERR_CNT	Correctable EDAC error counter in SDRAM since last boot.
ECSN1815: MRAM1_EDAC_UNCORR_CNT	MRAM1 uncorrectable edac 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 MIL-STD-1553B manager
ECSN1818: STAT_1_MILMAN_LASTERROR	Last error of MIL-STD-1553B 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

Parameter	Description
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.

2.4.2 Telecommand telemetry (Raw telemetry) generation

The commands sent to CaSSIS are echoed in the spacecraft telemetry (APID 346). This telemetry is received from the EDDS in the form of a data file and text report file. The data file contains a concatenation of spacecraft packets, with the text file containing a human readable report of the commands sent by the spacecraft to CaSSIS. The telecommands from the data file are extracted and saved to a report file and IDL structure for validation. This output report file/IDL structures contains information about whether specific commands sent to CaSSIS are recognised and when commands were sent (see Section 3.2 for further discussion of telecommand validation). Telecommand telemetry is extracted using IDL pipeline routines shown in Table 11.

Table 11: Telecommand telemetry extraction routines

TC TM Conversion Routines				
Procedure/function name	**Version**	**Description**	**Author**	**Call**
c_top_batch_tc_extract	V1.3	To make a batch conversion of TC reports packets into directory structure	NT	c_top_batch_tc_extract,top_directory [,status,HELP=HELP,mission_phase=mission_phase, sub_dir_filter=sub_dir_filter,first_command_time=first_command_time]
c_extract_cassis_tc	V1.01	To extract TCs sent to CaSSIS from spacecraft	NT	c_extract_cassis_tc,filename,output,status,debug=debug,HELP=HELP
c_read_command_table	V2.0	Read available CaSSIS commands	NT	c_read_command_table,commands [,filename=filename,help=help]
c_extract_tc_packet_report	V2.1	To extract commands sent to CaSSIS from the TC packet report	NT	c_extract_tc_packet_report,filename,extracted_commands [,status,debug=debug,widget=widget,listfile=listfile,HELP=HELP, ASCII=ASCII]

c_read_esoc_command_table	V1.1	To read science telemetry table	NT	c_read_esoc_command_table,esoc_command_table [,status,filename=filename,help=help]
c_read_fop_mapping_table	V1.1	To read flight operations plan table	NT	c_read_fop_mapping_table,fop_mapping_table [,status,filename=filename,help=help]

2.4.3 Level0 (Raw science data) generation

CaSSIS science data is received from the EDDS in the form of science files. Science files are collections of CaSSIS science packets, where each CaSSIS science packet contains data for a single CaSSIS sub-exposure/framelet. Level0 data refers to the raw data extracted from each of these science packets. That is, level0 data is CaSSIS image data where no calibrations have been performed and an individual piece of level0 data refers to a framelet observation. The level0 data is generated using IDL pipeline routines shown in Table 12. The level0 data generated by these routines are data files for each framelet, with an associated XML header file for each framelet. The framelet data files are 4-byte floating points in a 2D array, where the data file is stored as an unformatted binary. The XML header for the framelet contains HK data pertaining to that acquisition and geometry information taken from SPICE kernels, amongst other general meta information. Browse products for individual level0 framelets are not produced. For validation purposes, each of the individual CaSSIS science packets extracted from a given science file are output by the pipeline. A report file is also generated containing whether a specific CaSSIS science packet was extracted correctly (see Section 3.3 for further discussion of level0 data validation).

Table 12 Level0 science data generation routines

Procedure/function name	Version	Description	Author	Call
Level0 Science TM Conversion Routines				
c_top_read_edds	V1.05	Reads and separates CaSSIS packets from EDDS science files	NT	c_read_edds_system,filenames [,status,out_directory=out_directory,HELP=HELP,report_directory=

Procedure/function name	Version	Description	Author	Call
				report_directory]
c_read_edds_system	V1.05	To read the science packets from the EDDS, separate them, and write them to a temporary directory	NT	c_read_edds_system,filenames [,status,out_directory=out_directory,HELP=HELP,report_directory=report_directory]
c_read_sc_tm_table	V1.3	To read the science data telemetry definition table	NT	c_read_sc_tm_table,sc_tm_table [,sc_tm_table_numbers=sc_tm_table_numbers,data_position,status,filename=filename,help=help,version_number=version_number]
c_sc_file_resolution	V1.0	A high level script to go from a stored SC TM file to CaSSIS header and pixels by calling many of the above routines	NT	c_sc_file_resolution,file,header,framelet [,status,HELP=HELP]
c_sc_tm_frame_to_components	V1.4	To extract the data from the science telemetry frame	NT	c_sc_tm_frame_to_components,sc_tm_frame,sc_tm_table_numbers,cassis_frame, frame_attributes,frame_attribute_values,frame_data[,status,HELP=HELP,pehk_bytes=pehk_bytes,error_flag=error_flag]
c_translate_pehk	V1.0	To extract the values from the PE HK block and convert them into something useful	NT	c_translate_pehk,pehk,translation,attributes,attribute_values [,status,help=help,derived_hk_data=derived_hk_data]
c_number_bytes_expected	V1.0	To determine the number of bytes of image data to be expected and how many pixels that means, and the image sizes expected	NT	expected_bytes = c_number_bytes_expected (derived_hk_data [,status,image_sizes=image_sizes, HELP=HELP])
c_which_filter	V1.1	To determine which filter has been	NT	filter=c_which_filter(start_row,end_row [,STATUS,HELP=HELP])

Procedure/function name	Version	Description	Author	Call
		illuminated from the start and end rows transmitted		

2.4.4 Level1a (Partially processed science data) generation

Level1a data refers to level0 data that has been subject to a bias subtraction, division by a flat field and interpolation over bad pixels (see Section 2.4.9 for a list of all the calibration files used in the calibration pipeline). Furthermore, an absolute calibration is performed to convert from data number units (DN) into physical units (e.g. I/F for pixel values, conversion of DN values into voltages, temperatures etc.). Level1a data is output as a data file for each framelet, with a corresponding XML file containing header information in the same format as the level0 data. The header information from the corresponding level0 information is updated to denote that a bias subtraction, flat field division, bad pixel interpolation and absolute calibration has been applied to a given framelet. The IDL pipeline routines used to generate level1a data from level0 data are shown in Table 13. In addition to level1a data files and XML files for each framelet being generated, browse images of the level1a exposures are generated for validation purposes (an example of such an exposure is shown in Section 3.4). Note that browse products for individual level1a framelets are not produced, only browse products for a given level1a exposure.

The bias is generated using dedicated in-flight bias frame observations, where the overall bias for each of the 4 filters is an average of these observations. The flat field is generated for each of the 4 filters, with each flat field being the average of many different level0 framelets that were judged to have no significant features in the field of view. That is, only framelets that were judged to be largely homogenous were used to generate a flat field for a specific filter. The bad pixels interpolated over are those that have been found to have systematically minimal signal in all framelets for a specific filter. A linear interpolation using neighboring pixels is used.

Table 13 Level1a science data generation routines.

Procedure/function name	Version	Description	Author	Call
Level1a Science TM Conversion Routines				
c_top_batch_level0tolevel1a	V1.14	Collects level0 data to apply bias and flat field correction	NT	c_top_batch_level0tolevel1a,top_directory [,sub_dir_filter=sub_dir_filter,status,debug=debug,help=help,version_info=version_info,/no_composites,/no_zip]
c_read_image	V2.2	Read in framelet data file as an unformatted binary	NT	c_read_image,filename,oheader,image [,status,help=help,directory=directory,header_structure=header_structure]
c_compute_saturation	V1.01	Compute saturation mask for framelets	NT	c_compute_saturation,header_in,pixels_in,saturation_mask [,status,HELP=HELP,debug=debug,saturation_map_data=saturation_map_data,saturation_map_sigma=saturation_map_sigma,missing=missing,saturation_percent=saturation_percent,saturation_map_pan=saturation_map_pan]
c_data_shift	V0.08	Reconstruct framelet data in the event of framelet binning	NT	c_data_shift,header_in,pixels_in,header_out,pixels_out [,pixel_shift=pixel_shift,action=action,status,HELP=HELP,debug=debug,version_info=version_info]
c_remove_bias	V1.13	Subtract bias from framelet data	NT	c_remove_bias,header_in,pixels_in,header_out,pixels_out [,status,HELP=HELP,bias_short=bias_short,bias_long=bias_long,no_antoine=no_antoine,missing=missing]

Procedure/function name	Version	Description	Author	Call
c_remove_flat	V1.14	Remove flatfield from framelet data	NT	c_remove_flat,header_in,pixels_in,header_out,pixels_out [,status,HELP=HELP,flat=flat,version_info=version_info]
c_remove_badpix	V1.01	To subtract and interpolate over bad pixels	NT	c_remove_badpix,HEADER_IN,PIXELS_IN,HEADER_OUT,PIXELS_OUT [,STATUS]
c_expand	V1.1	Expand framelet data if it is binned	NT	c_expand,header_in,pixels_in,header_out,pixels_out,performed [,status,HELP=HELP,debug=debug]
c_absolute_calibration	V1.1	Perform absolute calibration from DN to I/F	NT	c_absolute_calibration,header_in,pixels_in,header_out,pixels_out,conversion_factors=conversion_factors[,unit=unit,status,HELP=HELP,debug=debug]
c_update_history	V2.2	Update XML header with calibrations performed on level0 data	NT	oOutput=c_update_history(oINPUT,process,routine,routine_version [,status,version_date=version_date,help=help])
c_make_sensor_composites	V1.05	Output individual exposures as browse images	NT	c_make_sensor_composites,filelist,in_directory=in_directory,out_directory=out_directory [,status,debug=debug,HELP=HELP, tvscale=tvscale]

2.4.5 Level1 (partially processed science data) generation

Level1 data refers to level1a data where the XML headers have been updated with the command that was issued to the instrument to produce a given level1a dataset. That is, level1a framelet data files are identical to level1 framelet data files. It is only the corresponding XML file for each framelet that is updated to produce the level1 data from the level1a data. The IDL pipeline routines used to generate the level1 data from the level1a data are shown in Table 14.

Table 14 Level1 science data generation routines.

Procedure/function name	Version	Description	Author	Call
Level1 Science TM Conversion Routines				
c_top_batch_level1atolevel1	V1.11	Updates level1a headers with imaging command used for image	NT	c_top_batch_level1atolevel1,top_directory,sub_dir_filter=sub_dir_filter [,/no_straylight,/straylight_composite,status,debug=debug,HELP=HELP,version_info=version_info]
c_tc_verify_execution	V1.04	Verify the TC execution and link the command to the image	NT	c_tc_verify_execution,top_directory[,sub_dir_filter=sub_dir_filter,image_parameter_table=image_parameter_table,status,HELP=HELP,debug=debug,version_info=version_info]
c_insert_element	V1.0	Insert element into header	NT	out=c_insert_element(oInput,blockname,parent,attributes,attribute_values,text [,status,HELP=HELP])

2.4.6 Level1c (Calibrated science data) generation

During science phase operations it was found that level1 framelet images can show degradation from straylight contamination on the detector. This contamination has been sourced to indirect sunlight reflecting off part of the detector sun-shield and into the detector itself. This straylight contamination was found to be stable between different framelet images, allowing for the contamination to be modelled by the University of Bern and removed from the level1 products. An example of a level1 exposure before and after a straylight calibration is performed is shown in Figure 5 in the left and right panels respectively. Furthermore, it was identified that applying the straylight correction to the level1 products revealed that neighboring framelets can have systematic brightness offsets between them. From comparing the overlap region of neighboring framelets, this brightness offset is identified and calibrated for using tools developed by the University of Bern. An example of before and after this framelet offset calibration has been applied is shown in Figure 6 in the left and right panels respectively. Note that this example image shows the effect of the framelet brightness offset when the framelets have been stitched together for ease of demonstration. Level1 products that have gone through a straylight and framelet offset calibration are referred to as the level1c products. Results of the straylight and framelet offset calibration are output for validation purposes (see Section 3.6). The IDL pipeline routines used for the level1 -> level1c data generation are shown in Table 15.

In the same way as previous data levels, level1c products are stored as data files for each framelet, with a corresponding XML header file. The framelet data files are 4-byte floating points in a 2D array, where the data file is an unformatted binary. The corresponding XML header files are updated to denote that a straylight and framelet brightness offset correction has been applied.

Table 15 Level1c science data generation routines

Procedure/function name	Version	Description	Author	Call
Level1c Science TM Conversion Routines				
c_correct_straylight_level1	V2.03	Correction for straylight and framelet brightness offset	NT	c_correct_straylight_level1, data_dir,cassis_calib [, FIRST_OBS=first_obs, LAST_OBS=last_obs, NEG_STRAY_COR=neg_stray_cor, CALIB_DATA_PACKAGE=calib_data_package,status,HELP=HEL

Procedure/function name	Version	Description	Author	Call
				P,debug=debug,version_info=version_info]
c_dir_obs_str	V1.0	Identifies level1c data in a directory and generates an IDL structure with data parameters	NT	cdos = c_dir_obs_str(dir_read)

Figure 5: Level1 exposure before (left panel) and after (right panel) straylight correction

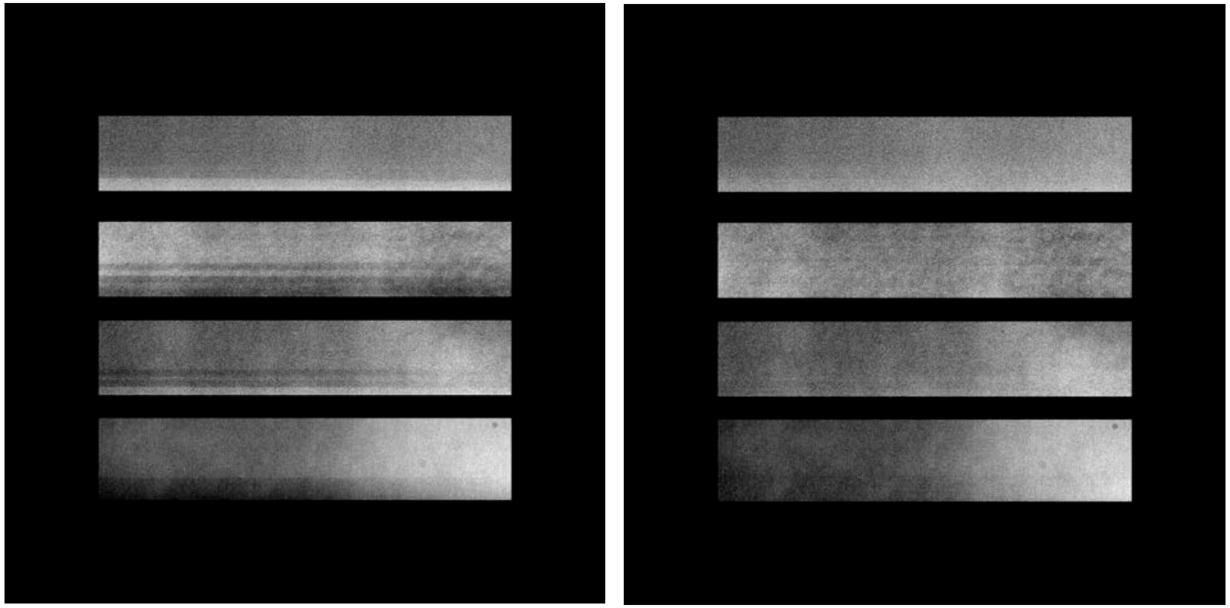
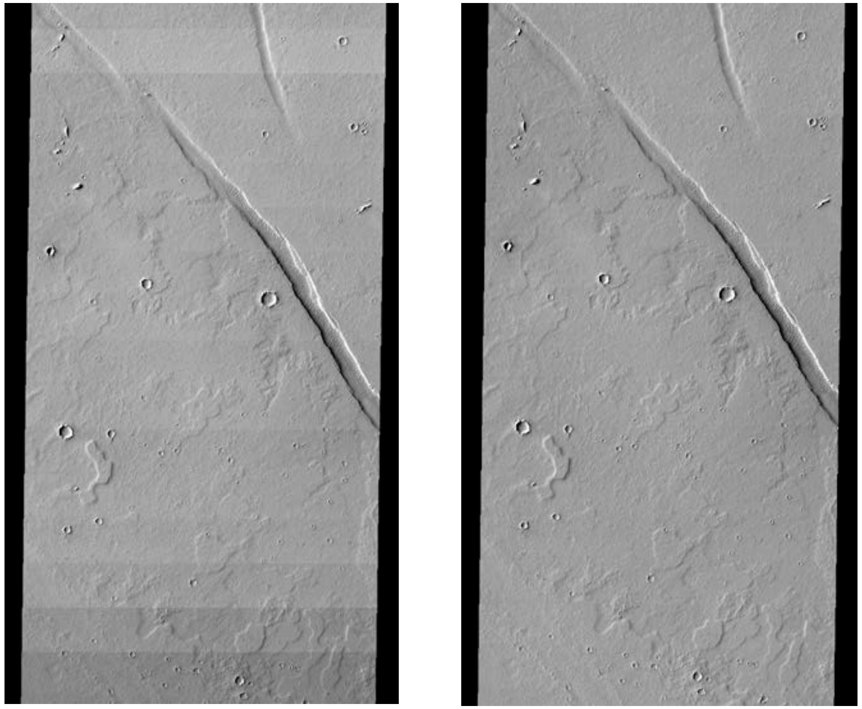


Figure 6: Level1 framelets before (left panel) and after (right panel) framelet offset correction. Framelets shown here are stitched together for clarity of the need for offset correction



2.4.7 Stitched (Calibrated science data) generation

Level1c framelets are stitched together using SPICE kernels to produce the full image swath in each individual filter used for a given observation. These images are referred to as stitched products. That is, a stitched product does not refer to a single level1c framelet, but all the level1c framelets for a given image, in a given filter, stitched together. The stitched image is stored as a data file as 4-byte floating points in a 2D unformatted binary array. Each stitched data file also has a corresponding XML header file, which is identical to a level1c XML header, with updated geometrical information to describe the footprint of the entire image and that the image is a stitched image rather than an individual framelet. The stitched images are also output as a stitched browse product for validation purposes, an example of which is given in Section 3.7. These stitched browse products are not geometrically corrected and stored as .jpg images, for quick viewing. The IDL pipeline routines used to produce the stitched data are shown in Table 16.

A report file is also generated which contains all the images which were planned to be acquired during a given observing period. If an image was acquired, then this report file is filled with meta information related to that acquisition including the id of the image, time of acquisition, filters used etc. This report file is used for validation purposes and to identify which targets, with which instrument specifications have been acquired.

Table 16 Stitched science data generation routines

Procedure/function name	Version	Description	Author	Call
Stitched Science TM Conversion Routines				
c_top_batch_stitch	V1.07	To produce stitched data, including stitched browse products	NT	c_top_batch_stitch,top_directory [,sub_dir_filter=sub_dir_filter,status,debug=debug,HELP=HELP]
c_read_imaging_command_parameters	V1.0	Reads in imaging commands and whether they succeeded or not	NT	output=c_read_imaging_command_parameters(filename [,status,HELP=HELP,debug=debug])
c_simple_stitch	V1.08	Generate stitched product using CaSSIS geometry	NT	c_simple_stitch,filelist,result [,status,HELP=HELP,debug=debug,result_bytscl=result_bytscl,/reverse]

2.4.8 Level3 (Geometry science data) generation

Level3 data products refer to level1c framelet products that have been geometrically calibrated using reconstructed SPICE kernels and combined to produce a single image for each filter used for an image acquisition. Level3 images are stored as data files as 4-byte floating points in a 2D unformatted binary array, with a corresponding XML header to denote that a geometric correction has been performed. Level3 products are produced at the University of Bern, using a pipeline produced by the University of Arizona which incorporate ISIS routines developed by the United States Geological Survey (see Figure 2). As part of this pipeline, framelet stitching is refined, with a smithed spacecraft CK kernel being produced for output. ISIS cube files are also produced for analysis. A level3 image in each of the individual filters is output as a .tiff file. The individual filter images are also combined to give a colour image, which is output as a PNG file (see Section 4.3.2 for a further discussion of products output with the level3 data).

2.4.9 Calibration products generation

The calibration products used for the level0 to level3 data generation includes:

- Bias frame – stored as a data file as 4-byte floating points in a 2D unformatted binary array. Dimensions of bias equal to window size in pixels (2048 x 2048).
- Flat field – stored as a data file as 4-byte floating points in a 2D unformatted binary array. Dimensions of flat field equal to window size in pixels (2048 x 2048).
- Bad pixel map – specific pixels to be removed included in calibration code. No separate bad pixel map produced.
- Straylight pattern – stored in IDL save file.

Specific details of the generation of these products can be found in the 'CaSSIS Calibration Report' to be archived with this document.

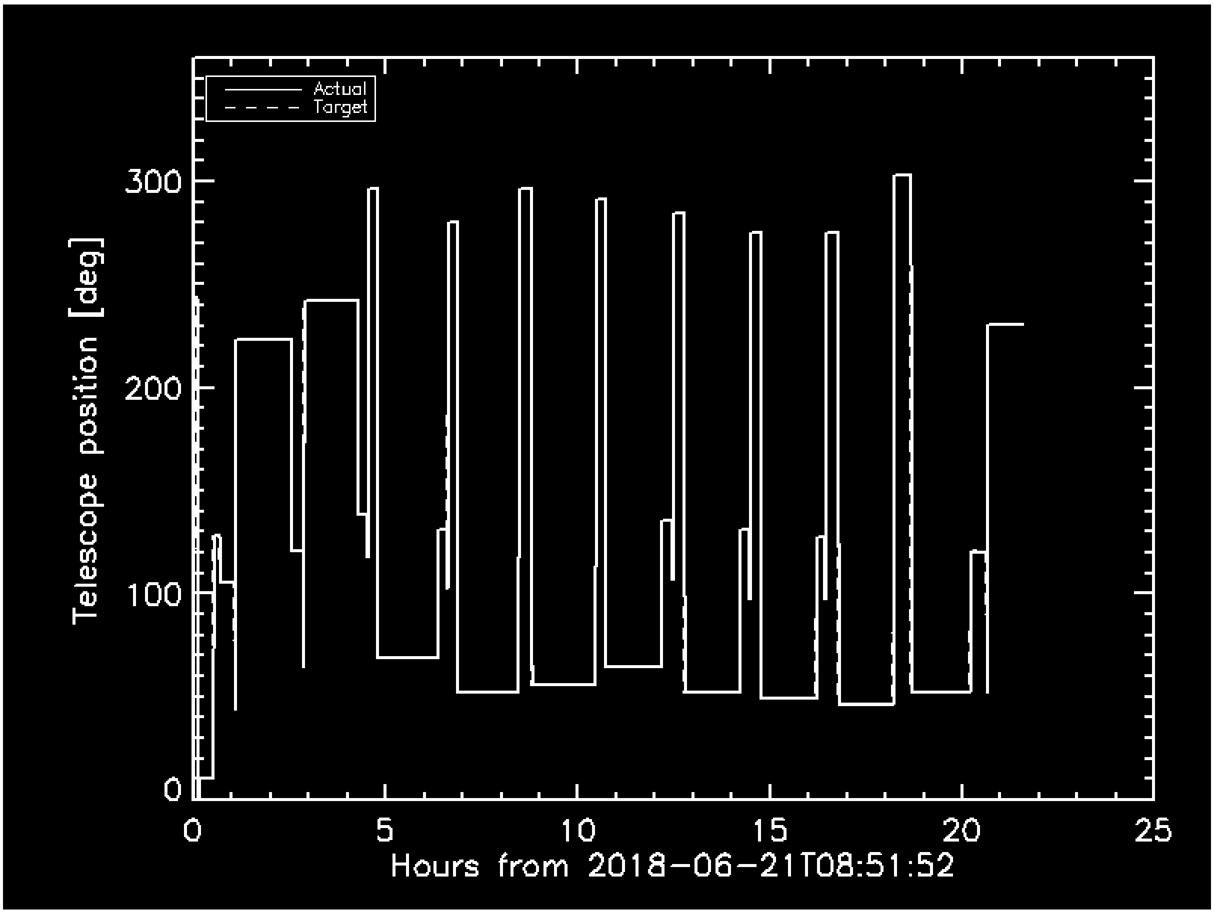
3 DATA VALIDATION

How the data from each part of the data reduction process described in Section 2 is validated is discussed during this section. Data validation is performed at UBE by the CaSSIS downlink team unless otherwise stated.

3.1 Housekeeping telemetry (Raw telemetry) validation

The housekeeping telemetry is output as IDL structure files along with graphical output for specific housekeeping variables (Section 2.4.1). An example output for the motor position is shown in Figure 7. 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 1553 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 7 Telescope position validation output



3.2 Telecommand telemetry (Raw telemetry) validation

Telecommands sent to CaSSIS are extracted and saved to a report file and IDL structure (Section 2.4.2). 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. An example part of this telecommand report file is shown below:

2018-09-04T15:58:21.000 ACSF001A VCS10004 CASSIS ON
2018-09-04T16:01:20.000 ACSF017A ECSZ0015 Change Operation Mode
2018-09-04T16:01:50.000 ACSF017A ECSZ0015 Change Operation Mode
2018-09-04T16:02:20.000 ACSF015A ECSZ0013 Dump
2018-09-04T16:02:50.000 ACSF021A ECSZ0025 Switch PE Power
2018-09-04T16:03:00.000 ACSF022A ECSZ0026 Switch PE Detector
2018-09-04T16:03:30.000 ACSF020A ECSZ0024 Switch Motor Power
2018-09-04T16:04:00.000 ACSF004A ECSZ0002 Move Motor Absolute
2018-09-04T16:07:00.000 ACSF004A ECSZ0002 Move Motor Absolute
2018-09-04T16:08:30.000 ACSF020A ECSZ0024 Switch Motor Power
2018-09-04T16:09:00.000 ACSF020A ECSZ0024 Switch Motor Power
2018-09-04T16:09:20.000 ACSF015A ECSZ0013 Dump
2018-09-04T16:19:22.000 ACSF020A ECSZ0024 Switch Motor Power
2018-09-04T16:19:52.000 ACSF004A ECSZ0002 Move Motor Absolute
2018-09-04T16:20:50.000 ACSF008A ECSZ0006 Set Parameter Table
2018-09-04T16:20:52.000 ACSF007A ECSZ0005 Set Parameter Value
2018-09-04T16:20:54.000 ACSF008A ECSZ0006 Set Parameter Table
2018-09-04T16:20:56.000 ACSF007A ECSZ0005 Set Parameter Value
2018-09-04T16:21:17.000 ACSF023A ECSZ0027 Prepare Image

The IDL structure file is used by validators for further analysis of the telecommands sent to CaSSIS during an observation period if necessary. Two additional checks are also made regarding telecommand execution. Firstly, that the set_parameter_table command is separate from the prepare_image_command. Both contain references to a parameter table in the flight software. The link between the set_parameter_table command and the prepare_image command is written to a report file as shown below:

Parameter table for image execution at 2016-11-26T22:32:05.000 found and linked to table at 2016-11-26T22:19:07.000000
Parameter table for image execution at 2016-11-26T22:35:34.888 found and linked to table at 2016-11-26T22:20:07.000000
Parameter table for image execution at 2016-11-26T22:36:35.888 found and linked to table at 2016-11-26T22:21:07.000000

3.3 Level0 data (Raw science data) validation

The level0 data is CaSSIS framelet information before any calibrations have been applied (Section 2.4.3). When extracting level0 data, a report file is generated containing an entry for each CaSSIS science packet that was extracted 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.

Browse products for level0 data are currently not automatically produced by the pipeline and are therefore not checked by validators. This is because raw data frames have poor contrast due to a lack of bias and flat calibration and hence validation of good acquisition and quality is not reasonable. However, browse products for level0 data can be generated for debugging purposes if a given framelet is seen to be abnormal.

3.4 Level1a data (Partially processed science data) validation

Level1a data refers to level0 data which has undergone a bias subtraction, flat field division and absolute calibration from DN to physical units. Browse products are produced for level1a exposures. An example level1a exposure with 4 filters is shown in Figure 8. Validators verify that the exposure in these browse products is within an acceptable range and that atmospheric phenomena have not degraded the data.

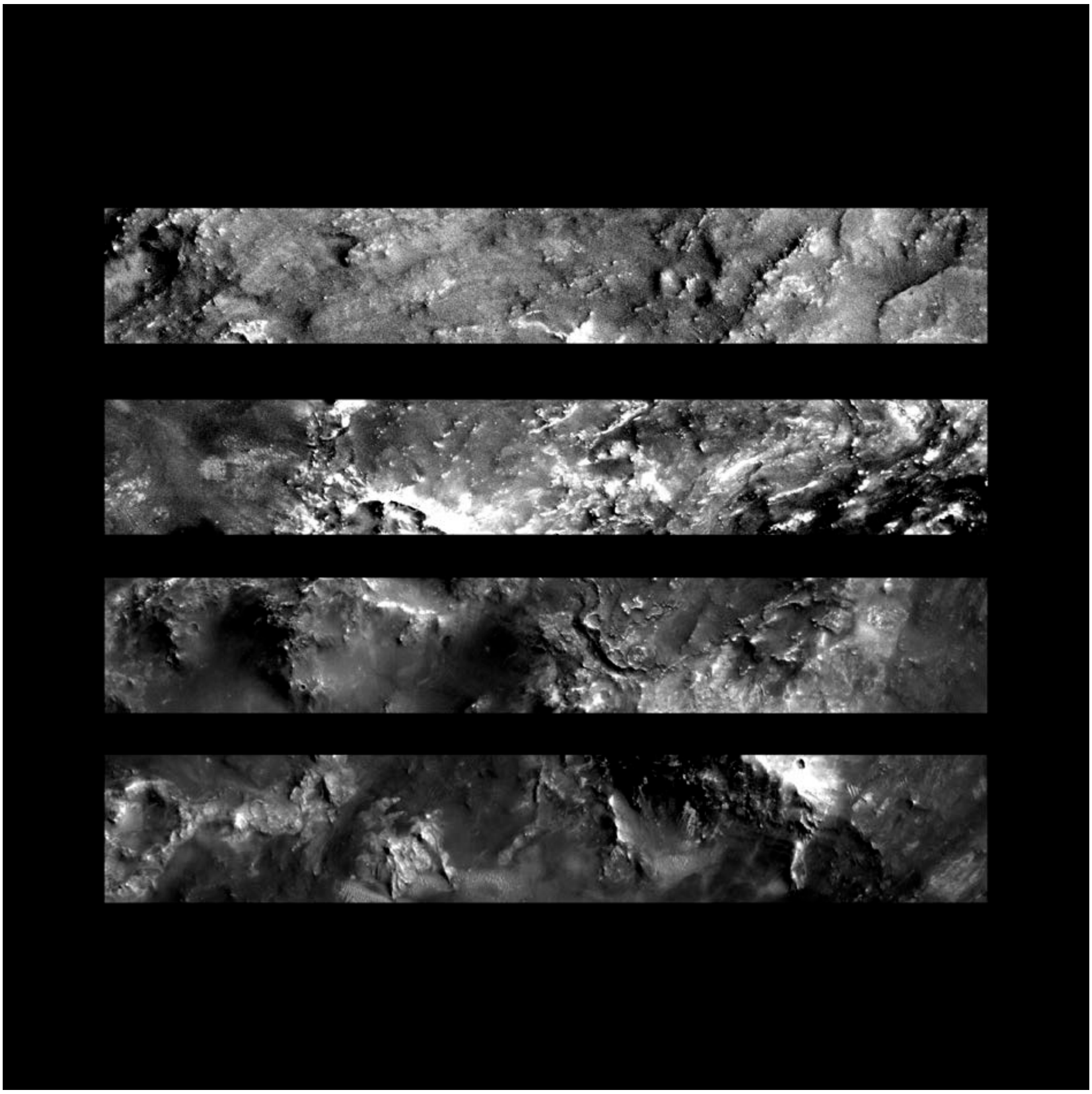
3.5 Level1 data (Partially processed science data) validation

Level1 data refers to level1a products which have had the imaging command added to the corresponding XML header file. As the pipeline routine which adds this imaging command was found to be stable, validators do not actively check to see if the correct imaging command was added to the XML header. Validators only check this imaging command as part of any debugging investigations.

3.6 Level1c data (Calibrated science data) validation

Straylight contamination and framelet brightness offsets were found to be present in some of the level1 data images and was removed to produce level1c data (Section 2.4.6). Currently no level1c browse products are produced by the pipeline. This is because level1c data are stitched together to make the stitched product (Section 2.4.7) where a browse product is produced. Validators check whether the straylight contamination and framelet brightness offset was calibrated out by therefore looking at the stitched browse product. Validators do check however, output report files which contain statistical information describing the success of the straylight and any framelet brightness offset removal.

Figure 8 An example level1a browse product

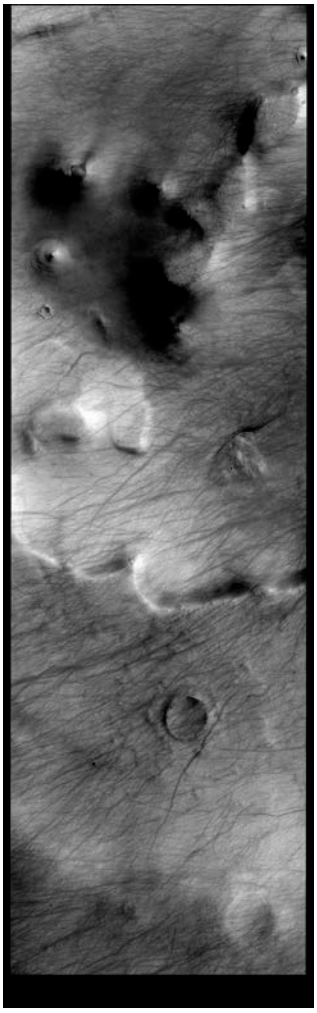


3.7 Stitched data (Calibrated science data) validation

Stitched data refers to the level1c framelets from a specific filter of a given image which are stitched together using geometrical information from the SPICE kernels (Section 2.4.7). Validators use the stitched browse products to check that the straylight and the framelet brightness offset calibration have performed as expected. Validators also check that the image is of an acceptable contrast (i.e. whether the exposure of the image gives an acceptable signal to noise in the image). Validators also check how well individual framelets have stitched together, which in turn allow validators to check the alignment of the telescope. An example of an image that is judged to have passed validator checks in shown in Figure 9.

Validators also check the report file generated for stitched products which contains information about which images were acquired and the corresponding meta information of acquired images. Checks are made to see if all expected images have been acquired and whether the meta information of acquired images reflects what was planned.

Figure 9 An example stitched browse product



3.8 Level3 data (Geometry data) validation

Level3 data refers to level1c data that has been geometrically corrected (Section 2.4.8). Validators check the footprint of the level3 images to check whether an image has been acquired close enough to where the image was planned to be observed. Validators also check the stitching between the geometrically corrected framelets to see if this has been performed correctly. Finally, validators check the level3 images where images from different filters have been combined to a single image, to see if there is any mis-match between the stitching of different filters.

If an image is judged to have a good acquisition, this image number is noted in the CaST database, where all of our targets are stored, that the image has been acquired successfully. If not, the image is marked in the database as incorrectly acquired and the target remains to be acquired. CaST will be open to the public so that is can be viewed which targets still need to be acquired successfully.

4 DATA ORGANISATION AND CONTENTS

This section describes the structure of how CaSSIS data is stored, the naming conventions used for data and explicitly what data is stored in the data structure.

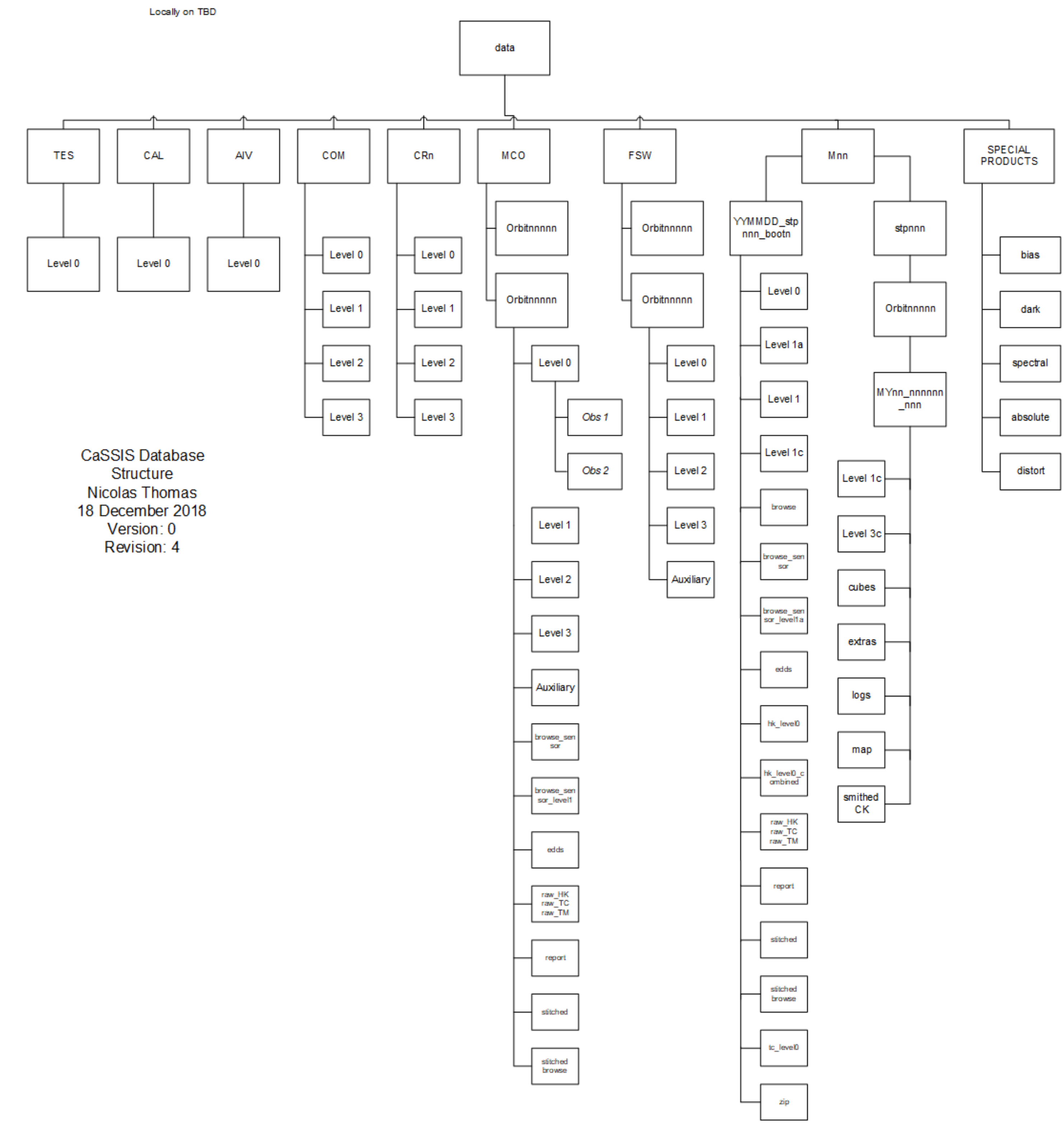
4.1 Data Storage Structure

CaSSIS data is held at the University of Bern in a directory structure shown in Figure 10. The acronyms used in Figure 10 are given in Table 17.

For science phase operations, the directory structure is different to previous mission phases. This is related to the need to reboot CaSSIS roughly once every 24hrs due to issues with the stability with the current version of the CaSSIS flight software described in Section 2.2. As CaSSIS is being rebooted roughly once every 24hrs, it was decided that the data acquired during a given STP would be split up into different reboot periods. For example, ‘boot1’ of a given STP shown in Figure 10, would refer to data acquired before the first reboot of that STP (or roughly 24hrs worth of data). Boot2 would refer to data acquired between the first and second reboot of CaSSIS during an STP etc.

A directory called ‘M03/180623_stp010_boot2’ therefore refers to data taken in MTP03, in STP010 (which started on the 23rd June 2018), during a rough 24hr observing period between the first and second reboot period of this STP.

Figure 10 Overview of Data Storage Structure



The generation of level3 data from level1c data requires the use of the pipeline produced by the University of Arizona (Section 2.4.8). This pipeline requires the level1c framelet data to have a different file naming convention to that output by the pipeline from the University of Bern that produces the level1c data (see Section 4.2 for a further discussion of naming conventions). To account for this, level1c output by the University of Bern pipeline is automatically copied into a separate directory structure, with filenames that allow for ingestion into the level3 data generation pipeline.

It is important to note that reference to 'University of Arizona' type products are used throughout this document. For clarity, these products are produced at the University of Bern *using* tools developed by the University of Arizona.

This is the data that is present in the 'stpnnn' directory in Figure 10. Level1c and the eventual level3 data are the only data that is contained within this part of the directory structure.

Table 17 Acronyms used in Figure 10

Acronym	Meaning
TES	Data acquired with the SELEX detector unit tester. Of some use for calibration but with incomplete metadata. Possible deliverable but requires considerable work.
CAL	Data acquired with the flight system on ground. Of some use for calibration but with incomplete metadata. Possible deliverable but requires considerable work.
ATL	Data acquired with the flight system on ground. Of some use for calibration but with incomplete metadata. Possible deliverable but requires considerable work.
COM	Data acquired during in-flight commissioning.
CRx (x=1-n)	Cruise check-out data.
MCO	Mars Capture Orbit data.
FSW	Flight software update data.
IOC	In orbit commissioning. Data acquired after Mars orbit insertion and before primary science phase.
Mnn	MTP phase where nn is the number of the MTP
stpnnn	STP phase where nnn is the number of the STP
YYMMDD_stpnnn_bootn	YYMMDD = Date of beginning of stp stpnnn = see above bootn = reboot number of CaSSIS during an STP
MYnn_nnnnnn_nnn	See text of Sec. 3.4
PRODUCTS	Bias, dark frames and associated calibration products of possible use for

Acronym	Meaning
	reductions. Possible deliverable but requires considerable work.

4.2 File Naming Convention

4.2.1 Framelet Data and Header Files

4.2.1.1 *University of Bern file naming convention*

The file naming conventions of the level0, 1a, 1 and 1c science phase framelet data files and XML header files that are found in the 'YYMMDD_stpnnn_bootn' part of the directory structure in Figure 10, have the following structure:

CAS-xxx-yyyy-mm-ddThh:mm:ss.sss-zzz-wwppp-vv.ext

The meanings for each part of this naming convention is shown in Table 18.

The stitched data has a similar naming convention that described above, with the remaining meanings for each part again being found in Table 18:

CAS-xxx-yyyy-mm-ddThh:mm:ss.sss-zzz-99999-C1.ext

4.2.1.2 *University of Arizona file naming convention*

The naming convention of the level1c data that is ingested into the pipeline to produce the level3 data is:

MYNN_oooooo_hhh_k_ppp_zzzww-C1.ext

Any part of this naming convention that is included in the naming convention above shares the same meaning in Table 18. Otherwise:

- NN = Martian year
- oooooo = orbit number
- hhh = orbit phase number
- k = number describing the image type 0 (individual), 1 (stereo 1), 2 (stereo 2), 3 (reserved)

The level3 file naming convention is slightly different. This is because the level3 products are stitched to produce a single image rather than individual framelets (see Section 2.4.8). The naming convention for the level3 products is:

MYNN_oooooo_hhh_k_zzz.ext,

where all variables describe previously defined parameters.

Table 18 Acronyms used in filenames

Code	Meaning
xxx	CAL = calibration ATL = ATLO COM = commissioning CRn = cruise MCO = Mars Capture Orbit FSW = flight software update and test IOC = in-orbit commissioning Mnn = MTP number
yyyy-mm-ddThh:mm:ss	Start time in standard format
zzz	RED = red area BLU = blue area PAN = pan area NIR = nir area EX1 = extra pixel area 1 EX2 = extra pixel area 2 EX3 = extra pixel area 3 EX4 = extra pixel area 4 EX5 = extra pixel area 5 EX6 = extra pixel area 6 FFR = full frame
ppp	Sub-exposure in sequence (000-999)
vv	Processing level 00 = raw A1 = radiometrically calibrated 01 = radiometrically calibrated with header including derived HK data (i.e. calibrated into physical units where possible) and command inserted C1 = straylight calibrated level 01 data
ext	File type dat = framelet data file xml = framelet header file

4.3 Data Contained in Data Storage Structure

The data contained within each of the directory from Figure 10 for science operations is described in the following section. University of Bern products are referred to as products found in the 'Mnn/YYMMDD_stpnn_bootn' directory structure in Figure 10. University of Arizona type products are referred to as products found in the 'Mnn/stpnnn' directory structure in Figure 10 (remembering that University of Arizona products are products generated at the University of Bern using University of Arizona tools).

4.3.1 University of Bern products

The contents of each directory in the overall 'Mnn/YYMMDD_stpnn_bootn' directory from Figure 10 are described here.

4.3.1.1 *Level0*

Contains level0 (raw science data) framelet data (data files and associated header XML files), with file naming convention described in Section 4.2.1.1.

4.3.1.2 *Level1a*

Contains level1a (partially processed science data) framelet data (data files and associated header XML files), with file naming convention described in Section 4.2.1.1.

4.3.1.3 *Level1*

Contains level1 (partially processed science data) framelet data (data files and associated header XML files), with file naming convention described in Section 4.2.1.1.

4.3.1.4 *Level1c*

Contains level1c (calibrated science data) framelet data (data files and associated header XML files), with file naming convention described in Section 4.2.1.1.

4.3.1.5 *browse*

Temporary directory used during level0 -> level1c calibration. Contains no data.

4.3.1.6 *browse_sensor*

Temporary directory used during level0 -> level1c calibration. Contains no data.

4.3.1.7 *browse_sensor_level1a*

Level1a (partially processed science data) exposure browse products, stored as jpg files. Naming convention is similar to that in Section 4.2.1.1 with slight change:

CAS-xxx-yyyy-mm-ddThh:mm:ss.sss-CMP-10ppp-A1_sensor.jpg

4.3.1.8 *edds*

Contains science files taken from the EDDS which contain CaSSIS science data.

4.3.1.9 *hk_level0*

Temporary directory used during level0 -> level1c calibration. Contains no data.

4.3.1.10 *hk_level0_combined*

Contains the extracted housekeeping data (raw telemetry data). As stated in Section 2.4.1 the housekeeping data is extracted according to one of the seven frame types. These frames are saved as IDL structure files with the corresponding integer frame value in the filename. IDL structure files are saved using both binary and real numbers. The structure file with '_calibrated' in the filename corresponds to the IDL structure file saved using real numbers.

Useful housekeeping variables are also output as .jpg files in this directory.

4.3.1.11 *raw_HK*

Contains the raw housekeeping telemetry queried from the EDDS.

4.3.1.12 *raw_TC*

Contains the raw telecommand data and the telecommand report queried from the EDDS.

4.3.1.13 *raw_TM*

CaSSIS science packets extracted from the science files queried from the EDDS.

4.3.1.14 *report*

The report directory contains all report files generated during data reduction with the University of Bern pipeline. The report files that are generated are as follows (the file names follow naming convention shown in Table 17):

- **YYMMDD_stpnnn_bootn_report.txt**: contains information on whether CaSSIS science packet identified as a framelet.
- **YYMMDD_stpnnn_bootn_report_tc.txt**: contains extracted telecommands from telemetry.
- **YYMMDD_stpnnn_bootn_tc_verification.txt**: contains whether there is a link between the set_parameter_table and prepare_image commands.
- **YYMMDD_stpnnn_bootn_tc_verification2.txt**: whether any images have any missing data.
- **YYMMDD_stpnnn_bootn_header_data.txt**: meta information about acquired images.
- **edds_depacketization_report_file.txt**: describes the science files that have been recognised by the pipeline and the CaSSIS science packets that have been extracted.
- **planned_completion.csv**: meta information about acquired images
- **YYMMDD_stpnnn_bootn_imaging_command_parameters.csv**: command parameters used for a given image acquisition.
- **YYMMDD_stpnnn_bootn_framelet_listings.sav**: IDL structure file containing geometric information for each framelet extracted from the SPICE kernels.
- **photometric_cor/**: sub-directory that contains results of the statistical analysis that is performed to calibrate framelets for straylight and any brightness offset.

4.3.1.15 *stitched*

Contains data file and corresponding XML files of level1c (calibrated) framelets that have been stitched together to make the full image in a given filter.

4.3.1.16 *stitched_browse*

Contains .jpg images of the stitched data.

4.3.1.17 *tc_level0*

Contains two IDL structure files describing the commands extracted from the raw telecommand data queried from the EDDS and whether these commands were recognised.

4.3.1.18 *zip*

Contains file zips of level0, 1, stitched and housekeeping data.

4.3.2 University of Arizona products (generated at the University of Bern)

4.3.2.1 *level1c*

Level1c framelet data files and corresponding XML header files with a naming convention that can be recognised by the University of Arizona pipeline.

4.3.2.2 *level3c*

Level3 (geometry) images, both data files and corresponding XML header files.

4.3.2.3 *cubes*

ISIS cube containing the geometrically corrected image.

4.3.2.4 *extras*

Browse images of geometrically corrected images from individual filters and filter combined images.

4.3.2.5 *logs*

Command line output from each stage of level1c->level3 calibration.

4.3.2.6 *maps*

Contains values of variables used during geometric correction of images.

4.3.2.7 *smithedCK*

Contains the geometrically smithed CK.

4.3.3 Calibration products (Special Products from Figure 10)

4.3.3.1 *Bias*
Contains the bias frame used during calibration.

4.3.3.2 *Dark*
Contains dark frames.

4.3.3.3 *Spectral*
Contains spectral products used during the calibration, including bad pixel map, flat field and straylight pattern.

4.3.3.4 *Absolute*
Contains absolute calibration information, which is since incorporated into radiometric pipeline.

4.3.3.5 *Distort*
Currently contains no data.

5 DATA PRODUCT FORMATS

This section summarizes the format of all image data products. This information has been stated in Section 2, however it is included specifically here for clarity. For a description of each of the data levels refer to Section 2. A discussion of what data is delivered to the PSA and any format issues with this delivery is described in Section 6.

5.1 Level0 (raw science data)

Level0 framelet data is stored as data file, with associated data being 4-byte floating points that are stored in a 2D array. The corresponding header file for each framelet is stored as a XML file.

5.2 Level1a (partially processed science data)

Level1a framelet data is stored as data file, with associated data being 4-byte floating points that are stored in a 2D array. The corresponding header file for each framelet is stored as a XML file.

5.3 Level1 (partially process science data)

Level1 framelet data is stored as data file, with associated data being 4-byte floating points that are stored in a 2D array. The corresponding header file for each framelet is stored as a XML file.

5.4 Level1c (calibrated science data)

Level1c framelet data is stored as data file, with associated data being 4-byte floating points that are stored in a 2D array. The corresponding header file for each framelet is stored as a XML file. An example level1c XML header file is given in Section 5.7.

5.5 Stitched (calibrated science data)

Stitched image data is stored as data file, with associated data being 4-byte floating points that are stored in a 2D array. The corresponding header file for each framelet is stored as a XML file. Browse products are generated for the stitched image data, which are stored as .jpg files.

5.6 Level3 (geometry data)

Level3 data images are stored as data files, with associated data being 4-byte floating points that are stored in a 2D array. The corresponding header files for each image are stored as a XML file. An example level3 XML header file is given in Section 5.8.

5.7 Example level1c XML header

Below is an example level1c header. Bold text is included where necessary to describe some variables for clarity. This bold text is not included in the actual level1c header.

<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<Product_Observational>

<Identification_Area>
<logical_identifier>TBD</logical_identifier>
<version_id>UNK</version_id>
<title>CaSSIS Data Record</title>
<information_model_version>TBD</information_model_version>
<product_class>Product_Observational</product_class> **:indicates header for an observed product**
<Modification_History>
<Modification_Detail>
<modification_date>2019-04-21T16:21:23</modification_date> **:time when header file initially generated**
<description>Header_Creation: c_new_header</description>**:code used to initially generate header**
<version_id>V3.2</version_id>**:version of c_new_header**
<version_date>16-Feb-2017</version_date>**:date of latest version of c_new_header**
</Modification_Detail>
<Modification_Detail>
<modification_date>2019-04-21T16:21:23</modification_date>**:time when SC TM packets extracted**
<description>SC TM Conversion: c_sc_file_resolution</description>**:code used to extract SC TM packets**

<version_id>V1.5</version_id>**:version of code used to extract SC TM packets**
<version_date>22-Mar-2018</version_date>**:date of latest version of c_sc_file_resolution**
</Modification_Detail>
<Modification_Detail>
<modification_date>2019-04-21T16:21:23</modification_date>**:time when level0 data extracted**
<description>SC TM Conversion: c_batch_sc_tm_packets</description>**:code used to extract level0 data**
<version_id>V1.35</version_id>**:version of code used to extract level0 data**
<version_date>07-Feb-2019</version_date>**:date of latest version of c_batch_sc_tm_packets**
</Modification_Detail>
<Modification_Detail>
<modification_date>2019-04-21T17:09:52</modification_date>**:time of bias subtraction**
<description>Bias Subtraction (bias_short_190313.dat): c_remove_bias</description>**:bias used**
<version_id>V1.13</version_id>**:version of code used to subtract bias**
<version_date>13-Mar-2019</version_date>**:date of latest version of bias subtraction code**
</Modification_Detail>
<Modification_Detail>
<modification_date>2019-04-21T17:09:52</modification_date>**:time of flat field removal**
<description>Flat field removal (flat_field_190313.dat): c_remove_flat</description>**:flat field used**
<version_id>V1.14</version_id>**:latest version of flat removal code**
<version_date>13-Mar-2019</version_date>**:date of the latest version of flat removal code**
</Modification_Detail>
<Modification_Detail>
<modification_date>2019-04-21T17:09:52</modification_date>**:time of bad pixel removal**
<description>Bad pixel removal (1 pixels replaced): c_remove_badpix</description>**:number of bad pixels removed and code which does this**
<version_id>V1.01</version_id>**:latest version of bad pixel removal code**
<version_date>03-Apr-2019</version_date>**:date of the latest version of bad pixel removal code**
</Modification_Detail>
<Modification_Detail>
<modification_date>2019-04-21T17:09:52</modification_date>**:time of unbinning of data**
<description>Expansion: c_expand</description>**:code that unbins data**
<version_id>V1.1</version_id>**:version of code that unbins data**
</Modification_Detail>
<Modification_Detail>
<modification_date>2019-04-21T17:09:52</modification_date>**:time of absolute calibration of data**
<description>Absolute_Calibration: c_absolute_calibration</description>**:code used for absolute calibration**
<version_id>V1.1</version_id>**:version of code used for absolute calibration**
</Modification_Detail>
<Modification_Detail>
<modification_date>2019-04-21T17:09:52</modification_date>**:time of level 0 to 1a calibration**

<description>SC TM Conversion: c_top_batch_level0tolevel1a</description>**:code used for level0 to 1a calibration**
<version_id>V1.14</version_id>**:version of code used for level0 to 1a calibration**
<version_date>03-Apr-2019</version_date>**:date of latest version of level0 to 1a calibration code**
</Modification_Detail>
<Modification_Detail>
<modification_date>2019-04-21T17:35:52</modification_date>**:date of level1a to 1 calibration**
<description>Command_Verification: c_top_batch_level1atolevel1</description>**:code used for level1a to 1 calibration**
<version_id>V1.11</version_id>**:version of code used for level1a to 1 calibration**
</Modification_Detail>
<Modification_Detail>
<modification_date>2019-04-21T18:00:40</modification_date>**:time of straylight removal**
<description>Photometric_correction: c_correct_straylight_level1</description>**:code used for straylight removal**
<version_id>V2.01</version_id>**:version of code used for straylight calibration**
</Modification_Detail>
</Modification_History>
<Producer_data>
<Producer_full_name>Nicolas Thomas</Producer_full_name>
<Producer_id>UBE</Producer_id>
<Producer_institution_name>Physikalisches Inst., Universitaet Bern</Producer_institution_name>
<Citation_Information>Thomas, N., Cremonese, G., Ziethe, R., Gerber, M., et al. The Colour and Stereo Surface Imaging System (CaSSIS) for the ExoMars Trace Gas Orbiter. Space Science Reviews, submitted.</Citation_Information>
</Producer_data>
<Product_Id>M0720181006163007579BLU0300000</Product_Id>**:Unique ID of framelet**
<CTF_Id>MY34_003880_344_0</CTF_Id>**:Name of image framelet is part of**
<BundleLID>urn:esa:psa:em16_tgo_cas</BundleLID>**:ID of the bundle framelet will be delivered in**
<stp>025</stp>
<mtp>M007</mtp>
<Radiometric_Pipeline_Version_Number>v1.01</Radiometric_Pipeline_Version_Number>
</Identification_Area>

<Observation_Area>
<Science_Facets bandwidth="Broad" discipline_name="Imaging" domain="Surface" wavelength_range="Visible"/>**:imaging characteristics**
<Investigation_Area>
<Instrument_Host_Id>TGO</Instrument_Host_Id>
<Instrument_Host_Name>TRACE GAS ORBITER</Instrument_Host_Name>
<Mission_Id>TRACE GAS ORBITER</Mission_Id>
<Mission_Name>EXOMARS TRACE GAS ORBITER</Mission_Name>

</Investigation_Area>
<Observing_System>
<name>Colour and Stereo Surface Imaging System on Exomars Trace Gas Orbiter</name>
<description>The scientific imaging system of Exomars TGO</description>
<Observing_System_Component>
<name>TGO</name>
<type>Spacecraft</type>
<description>Instrument Host</description>
</Observing_System_Component>
<Observing_System_Component>
<name>CaSSIS</name>
<type>Instrument</type>
<description>PUSH-FRAME CMOS VISIBLE REFLECTING TELESCOPE</description>
</Observing_System_Component>
</Observing_System>
</Observation_Area>

<CaSSIS_Header>
<CaSSIS_General>
<INSTRUMENT_IFOV Unit="rad/px">1.143e-005</INSTRUMENT_IFOV>
<TELESCOPE_FOCAL_LENGTH Unit="M"> 0.8749</TELESCOPE_FOCAL_LENGTH>
<TELESCOPE_F_NUMBER> 6.48</TELESCOPE_F_NUMBER>
<TELESCOPE_TYPE>Three-mirror anastigmat with powered fold mirror</TELESCOPE_TYPE>
<DETECTOR_DESC>2D Array</DETECTOR_DESC>
<DETECTOR_PIXEL_HEIGHT Unit="MICRON"> 10.0</DETECTOR_PIXEL_HEIGHT>
<DETECTOR_PIXEL_WIDTH Unit="MICRON"> 10.0</DETECTOR_PIXEL_WIDTH>
<DETECTOR_TYPE>SI CMOS HYBRID (OSPREY 2K)</DETECTOR_TYPE>
<DETECTOR_READ_NOISE Unit="ELECTRON"> 61.0</DETECTOR_READ_NOISE>
<FILTERS_AVAILABLE>BLU RED NIR PAN</FILTERS_AVAILABLE>
</CaSSIS_General>
<FSW_HEADER CompressionRatio="512" **coded compression ratio and compressor selection bits in an 2 byte long value which were used to compress window stored in TM packet** CompressionRatio_Length="2" **length in bytes of compression ratio parameter** CompressionRatio_Tag="5" **unique tag indicating compression ratio in TM packet** Data_Length="415251" **length in bytes of data from TM packet** Data_Tag="160" **unique tag indicating data in tm packet** Error="0" **error code for data in TM packet** Error_Length="4" **length of error code in bytes** Error_Tag="9" **unique tag of error code in tm packet** ExposureTimestamp="2f04d306baaa9382" **on board time of acquisition** ExposureTimestamp_Length="8" **length of exposure time in bytes** ExposureTimestamp_Tag="11" **unique tag of acquisition time in tm packet** FRAME_HEADER="250B" **length of header in bytes** Offset="0" **offset in bytes in data length area where data starts in TM packet** Offset_Length="4" **length of offset length in bytes** Offset_Tag="7" **unique tag indicating offset parameter**
PEHK="029e000400452c5a4f05591a7905831aa325b03ad00000000000000000010000000000000000000000003

000000bd0aba0a890900000000880d00000000000000" **HK frame** PEHK_Length="64" **length in bytes of HK frame** PEHK_Tag="80" **unique tag indicating beginning of HK frame** Position="82732" **Telescope absolute position in milli degrees at time of acquisition** Position_Length="4" **length in bytes of motor position** Position_Tag="10" **unique tag indicating beginning of motor position** ScienceTM_Length="415421" **length in bytes of science TM packet** SequenceCounter="0" **sequence counter of exposure** SequenceCounter_Length="1" **length in bytes of sequence counter** SequenceCounter_Tag="4" **unique tag indicating beginning of sequence counter** Timestamp="2f04d307aace600d" **timestamp when the science packet was assembled and sent along SpW** Timestamp_Length="8" **length of timestamp parameter in bytes** Timestamp_Tag="1" **unique tag indicating timestamp parameter** TotalDataLength="415251" **number of bytes the actual window data contains** TotalDataLength_Length="4" **length in bytes of total data length** TotalDataLength_Tag="6" **unique tag indicating beginning of total data length** Type="0" **frame type** Type_Length="1" **length of frame type parameter in bytes** Type_Tag="8" **unique tag of frame type** UID="276383072" **unique id of image command** UID_Length="4" **length in bytes of unique id of image command** UID_Tag="2" **unique tag of image command** WindowCounter="3" **the window number of TM packet** WindowCounter_Length="1" **length of window counter in bytes** WindowCounter_Tag="3" **unique tag of window counter param**/>:

<PEHK_HEADER Address_Accessed="3" **PE address** Address_Contents="0" **address of contents in commanded address** Assumed_ROIC_frequency="5.000e+006" Binning_window_1="0" **binning factor of window 1** Binning_window_2="0" **binning factor of window 2** Binning_window_3="0" **binning factor of window 3** Binning_window_4="0" **binning factor of window 4** Binning_window_5="0" **binning factor of window 5** Binning_window_6="0" **binning factor of window 6** Detector_Status="1" **integer of whether detector is on or not** Exposure_Time="1.517e-003" **exposure time of framelet in seconds** Last_Event="0" Number_of_windows="4" PROTECTION_FLAG="0" **not used** Spare1="0" **not used** Spare2="0" **not used** Spare3="0" **not used** Status_Word="1" **not used** TEC_Control_Byte0="0" **not used** TEC_Control_Byte1="0" **not used** TEC_Control_Byte2="0" **not used** TEC_Control_Byte3="0" **not used** TEC_Control_Byte4="0" **not used** TEC_Control_Byte5="0" **not used** TEC_Control_Byte6="0" **not used** TEC_Control_Byte7="0" **not used** TEC_Control_Byte8="0" **not used** TEC_Control_Byte9="0" **not used** TEC_Current="0" **not used** TEC_Status="0" **not used** T_CH1="0" **not used** T_CH2="0" **not used** T_FPA1="2749" **temperature in FPA in milli deg** T_FPA2="2746" **temperature 2 in FPA in milli deg** T_PE="2441" **temperature in PE in milli deg** Test_Status="0" **whether test mode for detector is used** V25_LOSS_FLAG="0" **loss of 25V in detector** V75_LOSS_FLAG="0" **loss of 75V in detector** VDET_ANA_OVC="0"**whether overcurrent used** VDET_DIG_OVC="0" **whether overcurrent used** V_PE33="3464" **voltage in PE in milli volts** Window1_End_Col="1727" **end of window 1 width on detector in pixels** Window1_End_Row="633" **end of window 1 height on detector in pixels** Window1_Start_Col="320" **start of window 1 width on detector in pixels** Window1_Start_Row="354" **start of window 1 height on detector in pixels** Window2_End_Col="1727" **end of window 2 width on detector in pixels** Window2_End_Row="967" **end of window 2 height on detector in pixels** Window2_Start_Col="320" **start of window 2 width on detector in pixels** Window2_Start_Row="712" **start of window 2 height on detector in pixels** Window3_End_Col="1727" **end of window 3 width on detector in pixels** Window3_End_Row="1303" **end of window 3 height on detector in pixels** Window3_Start_Col="320" **start of window 3 width on detector in pixels** Window3_Start_Row="1048" **start of window 3 height on detector in pixels** Window4_End_Col="1727" **end of window 4 width on detector in pixels** Window4_End_Row="1664" **end of window 4 height on detector in pixels** Window4_Start_Col="320" **start of window width on detector in**

pixels Window4_Start_Row="1409" **start of window 4 height on detector in pixels** Window5_End_Col="63" **end of window 5 width in pixels on detector** Window5_End_Row="-1" **end of window 5 height on detector in pixels** Window5_Start_Col="0" **start of window 5 width on detector in pixels** Window5_Start_Row="0" **start of window 5 height on detector in pixels** Window6_End_Col="63" **end of window 6 width on detector in pixels** Window6_End_Row="-1" **end of window 6 height on detector in pixels** Window6_Start_Col="0" **start of window 6 width on detector in pixels** Window6_Start_Row="0" **start of window 6 height on detector in pixels**/>

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<OnboardAcquisitionSCLKTime Time_Base="sclk"> 80938682.43667</OnboardAcquisitionSCLKTime>
<MissionPhase Phase_Definition="CaSSIS">M07</MissionPhase>
<Filter Form="Acronym">BLU</Filter>
<TelescopeRotationAngle Value="deg"> 82.732</TelescopeRotationAngle>
<CompressionName Form="Text">JPEG-LS</CompressionName>
<CompressionValue Form="Text">0</CompressionValue>
<ActualCompressionRatio Value="Ratio">1.736</ActualCompressionRatio>
<RequestedCompressionRatio Value="Ratio">1.750</RequestedCompressionRatio>
<ISISUniqueID ID="String">M0720181006163007579BLU0300000</ISISUniqueID>**:Unique ID of framelet**
<CTFUniqueID ID="String">MY34_003880_344_0</CTFUniqueID>**:Name of image framelet is part of**
<Expanded Flag="N/A">1</Expanded>
<Saturation_Analysis Value_95_percent_FW="%"> 0.00</Saturation_Analysis>**:percentage of pixels saturated to 95%**
<Saturation_Analysis Value_99_percent_FW="%"> 0.00</Saturation_Analysis>**:percentage of pixels saturated to 99%**
<Saturation_Analysis Value_FW="%"> 0.00</Saturation_Analysis>**:percentage of saturated pixels**
<ABSOLUTE_CALIBRATION Units="#/DN"> 3.34911e-005</ABSOLUTE_CALIBRATION>**:number used for absolute calibration**
<EffectiveWavelength Value="nm">508.8</EffectiveWavelength>
<EffectiveBandwidth Value="nm">111.2</EffectiveBandwidth>
</DERIVED_HEADER_DATA>
<GEOMETRIC_DATA Description="Geometric data from SPICE kernels">**:geometric data for framelet**
<TARGET>Mars</TARGET>
<POINTING_RIGHT_ASCENSION Unit="deg (J2000)">290.1175</POINTING_RIGHT_ASCENSION>
<POINTING_DECLINATION Unit="deg (J2000)">-6.6926</POINTING_DECLINATION>
<HELIOCENTRIC_DISTANCE Unit="AU">1.3843647</HELIOCENTRIC_DISTANCE>
<MARSCENTRIC_DISTANCE Unit="km">3778.7</MARSCENTRIC_DISTANCE>
<GEOCENTRIC_DISTANCE Unit="AU">0.6253776</GEOCENTRIC_DISTANCE>
<PHASE_ANGLE_MARS Unit="deg">60.558</PHASE_ANGLE_MARS>
<PIXEL_SCALE_IMAGE_PLANE Unit="m/px">4.47</PIXEL_SCALE_IMAGE_PLANE>
<SOLAR_ELONGATION_ANGLE Unit="deg">119.441</SOLAR_ELONGATION_ANGLE>

<SUB_SPACECRAFT_LONGITUDE Unit="deg (East Planetocentric)">316.4170</SUB_SPACECRAFT_LONGITUDE>
<SUB_SPACECRAFT_LATITUDE Unit="deg (Planetocentric)">-16.2991</SUB_SPACECRAFT_LATITUDE>
<TGO_OFF_NADIR_ANGLE Unit="deg">0.001</TGO_OFF_NADIR_ANGLE>
<CASSIS_OFF_NADIR_ANGLE Unit="deg">10.001</CASSIS_OFF_NADIR_ANGLE>
<LOCAL_SOLAR_TIME Unit="hh:mm:ss">07:42:37</LOCAL_SOLAR_TIME>
<L_SUB_S Unit="deg">263.934</L_SUB_S>
<SUN_ANGLE_FROM_CASSIS_DETECTOR_PLANE Unit="deg">-30.020</SUN_ANGLE_FROM_CASSIS_DETECTOR_PLANE>
<SUN_AZIMUTH_WRT_CASSIS_DETECTOR_FRAME Unit="deg">88.688</SUN_AZIMUTH_WRT_CASSIS_DETECTOR_FRAME>
<BETA_ANGLE Unit="deg">60.436</BETA_ANGLE>
<LONGITUDE_IMAGE_CORNERS Unit="deg (East Planetocentric)">(316.766804, 316.610960, 316.615449, 316.771366)</LONGITUDE_IMAGE_CORNERS>**:longitude of corner of framelet**
<LATITUDE_IMAGE_CORNERS Unit="deg">(-15.268335, -15.234108, -15.214978, -15.249219)</LATITUDE_IMAGE_CORNERS>**:latitude of corner of framelet**
<PHASE_ANGLE_FILTER Unit="deg">59.988</PHASE_ANGLE_FILTER>
<INCIDENCE_ANGLE_FILTER Unit="deg">60.623</INCIDENCE_ANGLE_FILTER>
<EMISSION_ANGLE_FILTER Unit="deg">10.620</EMISSION_ANGLE_FILTER>
<TGO_GROUND_TRACK_VELOCITY Unit="km/s">2.9647</TGO_GROUND_TRACK_VELOCITY>
<TGO_GROUND_TRACK_VECTOR Unit="3 x km/s"> 1.0489, -0.0855, 2.7716</TGO_GROUND_TRACK_VECTOR>
<PREDICTED_MAXIMUM_EXPOSURE_TIME Unit="ms">1.5044</PREDICTED_MAXIMUM_EXPOSURE_TIME>
<PREDICTED_REQUIRED_REPETITION_FREQUENCY Unit="ms">346.6</PREDICTED_REQUIRED_REPETITION_FREQUENCY>
<SUB_CASSIS_LONGITUDE Unit="deg (East Planetocentric)">316.699854</SUB_CASSIS_LONGITUDE>**:longitude of centre of observing window**
<SUB_CASSIS_LATITUDE Unit="deg (Planetocentric)">-15.204816</SUB_CASSIS_LATITUDE>**:latitude of centre of observing window**
<FORWARD_ROTATION_ANGLE_REQUIRED Unit="deg">82.933</FORWARD_ROTATION_ANGLE_REQUIRED> **angle away from TGO x direction of framelet**
<SPICE_KERNEL_MISALIGNMENT_PREDICT Unit="deg">359.423</SPICE_KERNEL_MISALIGNMENT_PREDICT> **misalignment angle required to stitch framelet to neighbouring framelets**
<CASSIS_GROUND_TRACK_VELOCITY Unit="km/s">2.9696</CASSIS_GROUND_TRACK_VELOCITY>
<CASSIS_GROUND_TRACK_VECTOR Unit="3 x km/s"> 1.0294, -0.0226, 2.7854</CASSIS_GROUND_TRACK_VECTOR>
<CASSIS_GROUND_TRACK_FSA_VECTOR Unit="3 x Normalized"> 0.0099, -0.9816, 0.1909</CASSIS_GROUND_TRACK_FSA_VECTOR>
<LINE_OF_SIGHT_DISTANCE Unit="km"> 390.859</LINE_OF_SIGHT_DISTANCE>
<PIXEL_SCALE_SURFACE Unit="m/px"> 4.5508</PIXEL_SCALE_SURFACE>

<SPACECRAFT_DIRECTION_WITH_RESPECT_TO_NODE String="text">ASCENDING</SPACECRAFT_DIRECTION_WITH_RESPECT_TO_NODE>
<CASSIS_IMAGE_TYPE Number="index"> 0</CASSIS_IMAGE_TYPE>**:type of image 0=individual image, 1=first of stereo pair, 2=second of stereo pair**
<SUN_ELEVATION_ON_MINUS_Y Unit="deg"> -29.441</SUN_ELEVATION_ON_MINUS_Y>
<SUN_AZIMUTH_ON_MINUS_Y Unit="deg"> 270.001</SUN_AZIMUTH_ON_MINUS_Y>
<Kernels_Used Unit="N/A">em16_tgo_sc_slt_npo_001_02_20160314_20191102_f20180215_v03.bc,em16_tgo_sc_slt_npo_002_01_20180901_20240303_f20180215_v01.bc,em16_tgo_sc_smp_006_01_20180908_20181006_f20180215_v01.bc,em16_tgo_sc_smp_007_00_01_20181006_20181103_f20180215_v01.bc,em16_tgo_sc_smp_007_01_20181006_20181103_f20180215_v01.bc,em16_tgo_sc_smp_008_00_01_20181103_20181201_f20180215_v01.bc,em16_tgo_sc_smp_008_01_20181103_20181201_f20180215_v01.bc,em16_tgo_sc_smp_009_00_01_20181201_20181229_f20180215_v02.bc,em16_tgo_sc_smp_009_01_20181201_20181229_f20180215_v01.bc,em16_tgo_sc_smp_010_00_01_20181229_20190126_f20180215_v01.bc,em16_tgo_sc_smp_010_00_02_20181229_20190126_f20180215_v01.bc,em16_tgo_sc_smp_010_01_20181229_20190126_f20180215_v01.bc,em16_tgo_sc_smp_011_00_01_20190126_20190223_f20180215_v01.bc,em16_tgo_sc_smp_011_00_02_20190126_20190223_f20180215_v01.bc,em16_tgo_sc_smp_011_00_03_20190126_20190223_f20180215_v01.bc,em16_tgo_sc_smp_011_01_20190126_20190223_f20180215_v01.bc,em16_tgo_sc_smp_012_00_01_20190223_20190323_f20180215_v01.bc,em16_tgo_sc_smp_012_00_02_20190223_20190323_f20180215_v01.bc,em16_tgo_sc_smp_012_01_20190223_20190323_f20180215_v01.bc,em16_tgo_sc_smp_013_00_01_20190323_20190420_f20180215_v01.bc,em16_tgo_sc_smp_013_01_20190323_20190420_f20180215_v01.bc,em16_tgo_sc_smp_014_00_01_20190420_20190518_f20180215_v01.bc,em16_tgo_sc_smp_014_01_20190420_20190518_f20180215_v01.bc,em16_tgo_sc_smp_015_00_01_20190518_20190615_f20180215_v01.bc,em16_tgo_sc_fmp_001_01_20180421_20180519_f20180215_v04.bc,em16_tgo_sc_fmp_002_01_20180519_20180616_f20180215_v01.bc,em16_tgo_sc_fmp_003_01_20180616_20180714_f20180215_v01.bc,em16_tgo_sc_fmp_004_01_20180714_20180811_f20180215_v01.bc,em16_tgo_sc_fmp_005_01_20180811_20180908_f20180215_v01.bc,em16_tgo_sc_fmp_006_01_20180908_20181006_f20180215_v01.bc,em16_tgo_sc_fmp_007_01_20181006_20181103_f20180215_v01.bc,em16_tgo_sc_fmp_008_01_20181103_20181201_f20180215_v01.bc,em16_tgo_sc_fmp_009_01_20181201_20181229_f20180215_v01.bc,em16_tgo_sc_fmp_010_01_20181229_20190126_f20180215_v01.bc,em16_tgo_sc_fmp_011_01_20190126_20190223_f20180215_v01.bc,em16_tgo_sc_fmp_012_01_20190223_20190323_f20180215_v01.bc,em16_tgo_sc_fmp_013_01_20190323_20190420_f20180215_v01.bc,em16_tgo_sc_fmp_014_01_20190420_20190518_f20180215_v01.bc,em16_tgo_sc_fsp_065_01_20180222_20190406_s20190208_v01.bc,em16_tgo_sc_ssm_20180311_20181231_s20190208_v01.bc,em16_tgo_sc_ssm_20181231_20190210_s20190208_v01.bc,em16_tgo_sc_ssm_20190210_20190324_s20190208_v01.bc,cassis_ck_p_160312_191231_190329.bc,em16_tgo_v17.tf,em16_tgo_ops_v02.tf,rssd0002.tf,em16_tgo_cassis_v07.ti,em16_tgo_str_v02.ti,naif0012.tls,PCK00010.TPC,de-403-masses.TPC,em16_tgo_fict_20180215.tsc,em16_tgo_step_20190208.tsc,em16_tgo_struct_v00.bsp,em16_tgo_cog_v00.bsp,em16_tgo_flp_001_02_20160314_20191102_v01.bsp,em16_tgo_flp_002_01_20180901_20240303_v01.bsp,em16_tgo_fsp_048_01_20180227_20181111_v01.bsp,em16_tgo_fsp_065_01_20181120_20190429_v01.bsp,DE432s.BSP,mar097_20160314_20300101.bsp</Kernels_Used>
</GEOMETRIC_DATA>
<IMAGE_COMMAND Description="Derived from the command setting the parameter table for this image.">

<Parameter_Table_REF Parameter="ECSP0030">2</Parameter_Table_REF>
<T_exp Parameter="ECSP1000">158</T_exp>**:Exposure time (ms)**
<Num_exp Parameter="ECSP1001">40</Num_exp>**:Number of exposures for full image**
<Step_exp Parameter="ECSP1002">343000</Step_exp>**:Time between each exposure (ms)**
<RIOC_Freq Parameter="ECSP1003">0</RIOC_Freq>**:RIOC frequency (MHz)**
<Num_win Parameter="ECSP1004">4</Num_win>**:Number of exposure windows used out of total of 6**
<Bin_win1 Parameter="ECSP1005">0</Bin_win1>**:Binning factor for window 1**
<Bin_win2 Parameter="ECSP1006">0</Bin_win2>**:Binning factor for window 2**
<Bin_win3 Parameter="ECSP1007">0</Bin_win3>**:Binning factor for window 3**
<Bin_win4 Parameter="ECSP1008">0</Bin_win4>**:Binning factor for window 4**
<Bin_win5 Parameter="ECSP1009">0</Bin_win5>**:Binning factor for window 5 (Ignored)**
<Bin_win6 Parameter="ECSP100A">0</Bin_win6>**:Binning factor for window 6 (Ignored)**
<Win1_str Parameter="ECSP100B">2884292</Win1_str>**:Start of window 1 in pixels on detector**
<Win1_end Parameter="ECSP100C">13886708</Win1_end>**:End of window 1 in pixels on detector**
<Win2_str Parameter="ECSP100D">2885008</Win2_str>**:Start of window 2 in pixels on detector**
<Win2_end Parameter="ECSP100E">13887376</Win2_end>**:End of window 2 in pixels on detector**
<Win3_str Parameter="ECSP100F">2885680</Win3_str>**:Start of window 3 in pixels on detector**
<Win3_end Parameter="ECSP1010">13888048</Win3_end>**:End of window 3 in pixels on detector**
<Win4_str Parameter="ECSP1011">2886402</Win4_str>**:Start of window 4 in pixels on detector**
<Win4_end Parameter="ECSP1012">13888770</Win4_end>**:End of window 4 in pixels on detector**
<Win5_str Parameter="ECSP1013">0</Win5_str>**:Start of window 5 on detector (ignored)**
<Win5_end Parameter="ECSP1014">0</Win5_end>**:End of window 5 on detector (ignored)**
<Win6_str Parameter="ECSP1015">0</Win6_str>**:Start of window 6 on detector (ignored)**
<Win6_end Parameter="ECSP1016">0</Win6_end>**:End of window 6 on detector (ignored)**
<PE_test Parameter="ECSP1017">0</PE_test>**:Proximity electronics test flag**
<Win1_CompR Parameter="ECSP1018">0</Win1_CompR>**:Compression factor for window 1**
<Win2_CompR Parameter="ECSP1019">0</Win2_CompR>**:Compression factor for window 2**
<Win3_CompR Parameter="ECSP101A">0</Win3_CompR>**:Compression factor for window 3**
<Win4_CompR Parameter="ECSP101B">0</Win4_CompR>**:Compression factor for window 4**
<Win5_CompR Parameter="ECSP101C">0</Win5_CompR>**:Compression factor for window 5**
<Win6_CompR Parameter="ECSP101D">0</Win6_CompR>**:Compression factor for window 6**
<TEC_start Parameter="ECSP101E">0</TEC_start> **TEC start status – Not used**
<CRC Parameter="ECSP0006">36537</CRC> **CRC hexid to check prepare parameter table command**
<Unique_Identifier Parameter="Unique Identifier">276383072</Unique_Identifier> **unique id of image command**
<Coarse_Time Parameter="Coarse_Time">80938682</Coarse_Time> **time in seconds of image acquisition using TGO clock**
<Fine_Time Parameter="Fine_Time">11179264</Fine_Time> **time in ticks of image acquisition using TGO clock in hexid (1 tick = 1/65000 secs)**
<Parameter_Table_REF Parameter="Parameter Table REF">2</Parameter_Table_REF> **unique id of parameter table command**
<CRC Parameter="CRC">32273</CRC> **CRC hexid to check image command**

<Unique_Id_Decoded Parameter="Unique_Identifer_Decoded">10794560</Unique_Id_Decoded>
</IMAGE_COMMAND>
</CaSSIS_Header>

<Errors>
<ERROR_BLOCK>Listing</ERROR_BLOCK>
</Errors>

<File_Area_Observational>
<File>
<file_name>CAS-M07-2018-10-06T16.30.07.579-BLU-03000-C1</file_name>**:filename of framelet using UBE naming convention**
<creation_date_time>2019-04-21T18:00:40</creation_date_time>**:time of framelet creation during calibration**
<comment>CaSSIS specific XML header</comment>
<created_file_name>S:\Projects\CaSSIS\data_matt\M07\181006_stp025_boot1\level1c\CAS-M07-2018-10-06T16.30.07.579-BLU-03000-C1</created_file_name>
</File>
<Array_2D_Image>
<axes>2</axes> **:number of framelet dimensions (framelet width and height)**
<Axis_Array>
<axis_name>Sample</axis_name> **:framelet width axis**
<sequence_number>1</sequence_number> **:axis number (out of 2)**
<elements>1408</elements> **:width of framelet in pixels**
</Axis_Array>
<Axis_Array>
<axis_name>Line</axis_name> **:framelet height axis**
<sequence_number>2</sequence_number> **:axis number (out of 2)**
<elements>256</elements> **:height of framelet in pixels**
</Axis_Array>
<Element_Array>
<data_type>IEEE754LSBSingle</data_type> **fortran unformatted binary file type in PDSV4 format**
<idl_data_type>4</idl_data_type> **IDL data type of data (4 = float for example)**
<order>First_Index_Fastest</order> **First pixel position in PDSV4 format**
<unit>DN</unit>
<scaling_factor> 1.00</scaling_factor> **scaling factor to reduce data size (unused)**
<offset> 0.00</offset> **offset to reduce data size (unused)**
</Element_Array>
</Array_2D_Image>
</File_Area_Observational>

</Product_Observational>

5.8 Example level3 XML header


```
<?xml version="1.0" encoding="utf-8"?>
<?xml-model
href="https://pds.jpl.nasa.gov/datastandards/schema/released/geom/v1/PDS4_GEOM_1B00_1610.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="local/CASSIS_1010.sch" schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="http://pds.nasa.gov/pds4/cart/v1/PDS4_CART_1900.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="http://pds.nasa.gov/pds4/img/v1/PDS4_IMG_1A10_1510.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="http://pds.nasa.gov/pds4/disp/v1/PDS4_DISP_1B00.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1B00.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<Product_Observational xsi:schemaLocation="http://pds.nasa.gov/pds4/pds/v1
http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1B00.xsd http://pds.nasa.gov/pds4/disp/v1
http://pds.nasa.gov/pds4/disp/v1/PDS4_DISP_1B00.xsd http://pds.nasa.gov/pds4/img/v1
http://pds.nasa.gov/pds4/img/v1/PDS4_IMG_1A10_1510.xsd http://pds.nasa.gov/pds4/cart/v1
http://pds.nasa.gov/pds4/cart/v1/PDS4_CART_1900.xsd local local/CASSIS_1010.xsd
https://pds.jpl.nasa.gov/datastandards/schema/released/geom/v1
https://pds.jpl.nasa.gov/datastandards/schema/released/geom/v1/PDS4_GEOM_1B00_1610.xsd"
xmlns:geom="https://pds.jpl.nasa.gov/datastandards/schema/released/geom/v1"
xmlns:cart="http://pds.nasa.gov/pds4/cart/v1" xmlns:disp="http://pds.nasa.gov/pds4/disp/v1"
xmlns="http://pds.nasa.gov/pds4/pds/v1" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:img="http://pds.nasa.gov/pds4/img/v1" xmlns:cassis="local">
 <Identification_Area>
  <logical_identifier>urn:esa:psa:em16_tgo_frd:data_mosaic:my34_004821_329_1_blu</logical_identifier>
  <version_id>1.0</version_id>
  <title>PDS4 product exported from ISIS3 cube.</title>
  <information_model_version>1.11.0.0</information_model_version>
  <product_class>Product_Observational</product_class>
  <Alias_List>
   <Alias>
    <alternate_id>MY34_004821_329_1</alternate_id>
    <comment>CaSSIS Internal Identifier</comment>
   </Alias>
  </Alias_List>
  <Modification_History>
   <Modification_Detail>
```

```
    <modification_date>2019-06-25</modification_date>
    <version_id>1.0</version_id>
    <description>Created PDS4 output product from ISIS cube with the tgocassisrdrgen application from ISIS
version 3.7.0 .</description>
   </Modification_Detail>
  </Modification_History>
 </Identification_Area>
 <Observation_Area>
  <Time_Coordinates>
   <start_date_time>2018-12-22T16:39:14.411</start_date_time>
   <stop_date_time>2018-12-22T16:39:24.1852099</stop_date_time>
   <local_true_solar_time>13.083913183203</local_true_solar_time>
   <solar_longitude unit="deg">311.00155756128</solar_longitude>
  </Time_Coordinates>
  <Investigation_Area>
   <name>TRACE GAS ORBITER</name>
   <type>Mission</type>
   <Internal_Reference>
    <lid_reference>urn:esa:psa:context:investigation:mission.tgo</lid_reference>
    <reference_type>data_to_investigation</reference_type>
    <comment>This is the PDS4 logical identifier for the ExoMars Trace Gas Orbiter mission.</comment>
   </Internal_Reference>
  </Investigation_Area>
  <Observing_System>
   <Observing_System_Component>
    <name>TRACE GAS ORBITER</name>
    <type>Spacecraft</type>
   </Observing_System_Component>
   <Observing_System_Component>
    <name>CaSSIS</name>
    <type>Instrument</type>
   </Observing_System_Component>
  </Observing_System>
  <Target_Identification>
   <name>Mars</name>
   <type>Planet</type>
  </Target_Identification>
  <Mission_Area>
   <cassis:CaSSIS>
    <cassis:smithedck>true</cassis:smithedck>
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   </cassis:CaSSIS>
```

```
</Mission_Area>
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  <Local_Internal_Reference>
   <local_identifier_reference>Image_Array_Object</local_identifier_reference>
   <local_reference_type>display_settings_to_array</local_reference_type>
  </Local_Internal_Reference>
  <disp:Display_Direction>
   <disp:horizontal_display_axis>Sample</disp:horizontal_display_axis>
   <disp:horizontal_display_direction>Left to Right</disp:horizontal_display_direction>
   <disp:vertical_display_axis>Line</disp:vertical_display_axis>
   <disp:vertical_display_direction>Top to Bottom</disp:vertical_display_direction>
  </disp:Display_Direction>
 </disp:Display_Settings>
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   <local_identifier_reference>Image_Array_Object</local_identifier_reference>
   <local_reference_type>imaging_parameters_to_image_object</local_reference_type>
  </Local_Internal_Reference>
  <img:Image_Product_Information>
   <img:Filter>
    <img:filter_name>BLU</img:filter_name>
    <img:filter_id>BLU</img:filter_id>
    <img:bandwidth unit="nm">165</img:bandwidth>
    <img:center_filter_wavelength unit="nm">485</img:center_filter_wavelength>
   </img:Filter>
  </img:Image_Product_Information>
 </img:Imaging>
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   <local_identifier_reference>Image_Array_Object</local_identifier_reference>
   <local_reference_type>cartography_parameters_to_image_object</local_reference_type>
  </Local_Internal_Reference>
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   <cart:Bounding_Coordinates>
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    <cart:east_bounding_coordinate unit="deg">67.098785172111</cart:east_bounding_coordinate>
    <cart:north_bounding_coordinate unit="deg">-28.534679844963</cart:north_bounding_coordinate>
    <cart:south_bounding_coordinate unit="deg">-29.131067556925</cart:south_bounding_coordinate>
   </cart:Bounding_Coordinates>
  </cart:Spatial_Domain>
  <cart:Spatial_Reference_Information>
```

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   <cart:Horizontal_Coordinate_System_Definition>
    <cart:Planar>
     <cart:Map_Projection>
      <cart:map_projection_name>Equirectangular</cart:map_projection_name>
      <cart:Equirectangular>
       <cart:standard_parallel_1 unit="deg">-25.0</cart:standard_parallel_1>
       <cart:longitude_of_central_meridian unit="deg">180</cart:longitude_of_central_meridian>
       <cart:latitude_of_projection_origin unit="deg">0</cart:latitude_of_projection_origin>
      </cart:Equirectangular>
     </cart:Map_Projection>
     <cart:Planar_Coordinate_Information>
      <cart:planar_coordinate_encoding_method>Coordinate Pair</cart:planar_coordinate_encoding_method>
      <cart:Coordinate_Representation>
       <cart:pixel_resolution_x unit="m/pixel">4.0</cart:pixel_resolution_x>
       <cart:pixel_resolution_y unit="m/pixel">4.0</cart:pixel_resolution_y>
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       <cart:pixel_scale_y unit="pixel/deg">14802.982173518</cart:pixel_scale_y>
      </cart:Coordinate_Representation>
     </cart:Planar_Coordinate_Information>
     <cart:Geo_Transformation>
      <cart:upperleft_corner_x unit="m">-6073700.0</cart:upperleft_corner_x>
      <cart:upperleft_corner_y unit="m">-1689592.0</cart:upperleft_corner_y>
     </cart:Geo_Transformation>
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     <cart:semi_minor_radius unit="m">3392593.611</cart:semi_minor_radius>
     <cart:polar_radius unit="m">3392593.611</cart:polar_radius>
     <cart:longitude_direction>Positive East</cart:longitude_direction>
    </cart:Geodetic_Model>
   </cart:Horizontal_Coordinate_System_Definition>
  </cart:Spatial_Reference_Information>
 </cart:Cartography>
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   <geom:Display_Direction>
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    <geom:horizontal_display_direction>Left to Right</geom:horizontal_display_direction>
    <geom:vertical_display_axis>Sample</geom:vertical_display_axis>
    <geom:vertical_display_direction>Top to Bottom</geom:vertical_display_direction>
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```

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    <geom:Object_Orientation_North_East>
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     <geom:east_azimuth unit="deg">0</geom:east_azimuth>
     <geom:Reference_Frame_Identification>
      <geom:name>J2000</geom:name>
     </geom:Reference_Frame_Identification>
    </geom:Object_Orientation_North_East>
   </geom:Image_Display_Geometry>
   <geom:Geometry_Orbiter>
    <geom:geometry_reference_time_utc>2018-12-22T16:39:14.411Z</geom:geometry_reference_time_utc>
    <geom:Surface_Geometry>
     <geom:Surface_Geometry_Specific>
      <geom:subsolar_azimuth unit="deg">209.8741886421</geom:subsolar_azimuth>
     </geom:Surface_Geometry_Specific>
    </geom:Surface_Geometry>
    <geom:Illumination_Geometry>
     <geom:Illumination_Specific>
      <geom:reference_pixel_location>Center</geom:reference_pixel_location>
      <geom:incidence_angle unit="deg">18.114227041387</geom:incidence_angle>
      <geom:emission_angle unit="deg">12.806126354345</geom:emission_angle>
      <geom:phase_angle unit="deg">24.859728767759</geom:phase_angle>
     </geom:Illumination_Specific>
    </geom:Illumination_Geometry>
   </geom:Geometry_Orbiter>
  </geom:Geometry>
 </Discipline_Area>
</Observation_Area>
<File_Area_Observational>
 <File>
  <file_name>MY34_004821_329_1_BLU.dat</file_name>
 </File>
 <Array_2D_Image>
  <local_identifier>Image_Array_Object</local_identifier>
  <offset unit="byte">0</offset>
  <axes>2</axes>
  <axis_index_order>Last Index Fastest</axis_index_order>
  <description>Pixel values are in units of I/F (intensity/flux). I/F is defined as the ratio of the observed radiance
and the radiance of a 100% lambertian reflector with the sun and camera orthogonal to the observing
surface.</description>
  <Element_Array>
   <data_type>IEEE754LSBSingle</data_type>
   <scaling_factor>1.0</scaling_factor>
```

```
    &lt;value_offset&gt;0.0&lt;/value_offset&gt;
   &lt;/Element_Array&gt;
   &lt;Axis_Array&gt;
    &lt;axis_name&gt;Sample&lt;/axis_name&gt;
    &lt;elements&gt;3736&lt;/elements&gt;
    &lt;sequence_number&gt;1&lt;/sequence_number&gt;
   &lt;/Axis_Array&gt;
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    &lt;axis_name&gt;Line&lt;/axis_name&gt;
    &lt;elements&gt;8829&lt;/elements&gt;
    &lt;sequence_number&gt;2&lt;/sequence_number&gt;
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    &lt;high_representation_saturation&gt;-1.79769313486231571e+308&lt;/high_representation_saturation&gt;
    &lt;low_instrument_saturation&gt;-1.79769313486231531e+308&lt;/low_instrument_saturation&gt;
    &lt;low_representation_saturation&gt;-1.79769313486231511e+308&lt;/low_representation_saturation&gt;
   &lt;/Special_Constants&gt;
  &lt;/Array_2D_Image&gt;
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 &lt;CaSSIS_Header&gt;
  &lt;IDENTIFICATION_DATA&gt;
   &lt;observation_id&gt;MY34_004821_329_1&lt;/observation_id&gt;
  &lt;/IDENTIFICATION_DATA&gt;
  &lt;FSW_HEADER Timestamp="2f05388c5a0f8ee0"/&gt;
 &lt;/CaSSIS_Header&gt;
&lt;/Product_Observational&gt;
```

6 DATA ARCHIVING AND DATA DELIVERED TO THE PSA

All data products will be archived at the University of Bern. In addition, Level0, level1c, stitched browse and level3 products will be delivered to the PSA. An overview of the data archiving is shown in Figure 11 for reference.

Level0 and level1c products will not be formatted perfectly according to PDS4 guidelines. There are specific reasons for this. Our primary analysis software converts XML into structures. These structures do not maintain the header data nomenclature in PDSV4 but modify them to avoid duplication. This is a significant issue with the PDS standard. We propose to instead deliver our data in a PDSV4 similar format. This will comprise an XML header with most tags compatible to the PDS V4 standard and data files also compatible with that standard. The PSA can then write a straightforward parser to produce the required format.

Level3 data will be delivered according to PDS V4 format.

Immediately below, data archived and delivered to the PSA are described using the University of Bern data levels. Following this description, the data delivery is summarized using PSA nomenclature, including description of a CaSSIS PSA bundle.

All delivered data to the PSA will come from the University of Bern only and no other institution.

6.1 Data Archiving and PSA Delivery using University of Bern nomenclature

6.1.1 Level0 data delivery

The filename for each framelet data file and XML file follows the naming convention described in Section 4.2.1.1. For example, a framelet acquired at 2018-10-12T10:12:15.1234 (MTP007) in the BLU filter, where this framelet was the fifth of a full image to be acquired would have a data file and an XML file with the following filenames:

CAS-M07-2018-10-12T10:12:15.1234-BLU-005-00.dat
CAS-M07-2018-10-12T10:12:15.1234-BLU-005-00.xml.

Both the data file and the XML file for each framelet in a given image acquisition will be delivered to the PSA for archiving. For example, an image acquired in the BLU, NIR and PAN filters with 10 framelets would mean a total of 60 files being delivered to the PSA (3 filters, 10 framelets each with data and xml file) with a naming explicitly described above. For level0 data, raw framelet data files and xml files are delivered to the PSA only. No browse products are delivered.

6.1.2 Level1c data delivery

Level1c data is delivered to the PSA in exactly the same form as the level0 data, a data file and XML header file for each framelet, with no browse products.

6.1.3 Stitched browse data delivery

Stitched browse data refers to stitched level1c data, output as a browse product. A stitched browse product for every filter of a given level1c image acquisition will be delivered to the PSA as a .jpg file.

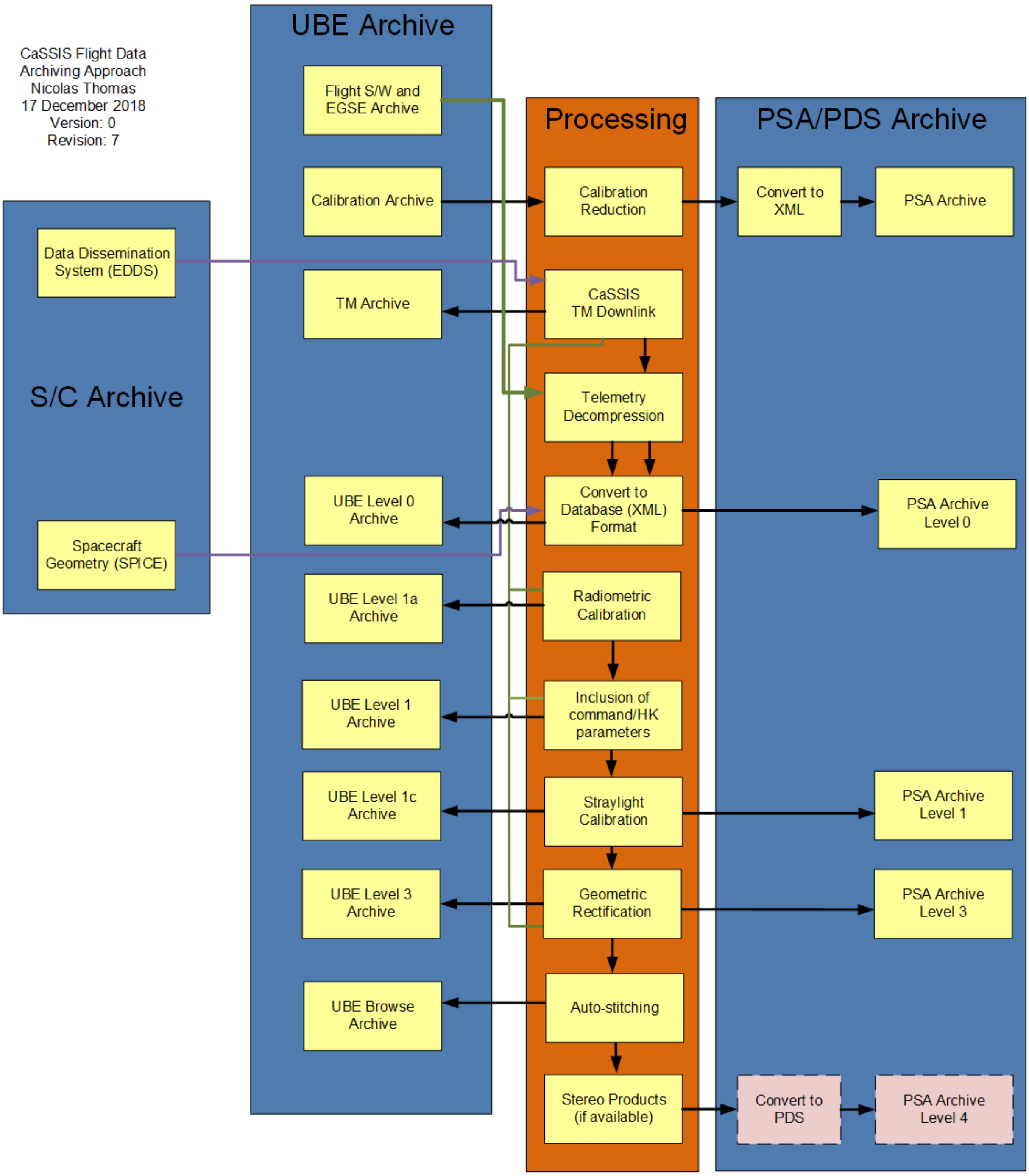

Figure 11 Data archiving overview

6.2 PSA data delivery using PSA nomenclature

6.2.1 Raw data

The raw data delivery to the PSA for each stage of the mission is the level0 data in a form described in Section 6.1.1. That is, a data file and a corresponding XML header file for each CaSSIS framelet in each filter for a given image exposure, in a format described in Section 5.1.

The level0 data nomenclature is identical between the University of Bern and the PSA as was shown in Table 2. See Section 4.2.1 for naming convention of raw data.

6.2.2 Partially Processed data

Partially processed data refers to level1a and level1 data in the University of Bern nomenclature (see Table 2).

For the main science phase of the mission, calibrated data is supplied to the PSA rather than partially processed data. That is, for the science phase, neither level1a or level1 products (partially processed products) are delivered to the PSA in favor of the level1c and stitched browse products (see Section 6.2.3).

A dataset of observations of Mars acquired during the Mars Capture Orbit had to be generated manually to correctly produce the level0 data. This accounted for incorrect shifts of the data within CaSSIS that occurred as the result of a flight software bug. This bug resulted in inaccurate calibration when using calibration files produced during ground testing. As an additional calibration had to be applied to generate this level0 data, it is described as being partially processed rather than raw (this is denoted in delivery schedule to the PSA in Section 6.3 as level0 data with FSW correction). This partially processed product has been delivered. It was also used as the basis for subsequent calibration of MCO data of the surface of Mars. Star data acquired during MCO has not been corrected for the FSW bug.

For the commissioning, Mars capture orbit and in orbit commissioning phases of the mission, raw data was only calibrated up to level1 (Section 2.4.5) rather than level1c (i.e. no straylight or framelet brightness offset correction). This data for the commissioning and Mars capture orbit data has since been delivered to the PSA. As level1 data is currently delivered to the PSA for these datasets, it is considered to be partially processed. Similarly, the in orbit commissioning phase of the mission has only been generated up to level1 and currently will be delivered to the PSA in this partially processed form.

See Section 4.2.1 for naming convention of partially processed data.

6.2.3 Calibrated data

Calibrated data refers to level1c in the University of Bern nomenclature and is the level1 data in PSA nomenclature (see Table 2).

Calibrated data is only delivered to the PSA for post-science mission epochs, in a form described in Section 6.1.2. That is, a data file and XML header file for each CaSSIS framelet observation, in a format described in Section 5.4.

See Section 4.2.1 for naming convention of calibrated data.

6.2.4 Browse data

Browse products are delivered to the PSA for stitched calibrated data. That is, browse products of level1c framelets (Uni Bern nomenclature) that have been stitched together to give the entire image swath for each individual filter of a given observation. These browse products are delivered as .jpg files, 1 for each filter used during an observation. **Corresponding xml labels for each of the .jpg images are TBD, but will be produced by the University of Bern once these labels have been defined.** See Section 4.2.1 for naming convention of browse data.

6.2.5 Calibration Products

Products used during the calibration procedure of images are planned to be delivered to the PSA. These include:

- Bias – stored as a data file as 4-byte floating points in a 2D unformatted binary array. Dimensions of bias equal to window size in pixels (2048 x 2048).
- Flat field – stored as a data file as 4-byte floating points in a 2D unformatted binary array. Dimensions of flat field equal to window size in pixels (2048 x 2048).
- Bad pixel map – specific pixels to be removed included in calibration code. No separate bad pixel map produced.
- Straylight pattern – stored in IDL save file.

The timescale for delivery of calibration products to the PSA is TBD. Current each of the calibration products do not have a corresponding xml header file. However the University of Bern plans to create these xml files for ingestion of calibration products into the PSA.

6.3 CaSSIS Data Bundle Organization

The general contents of an ExoMars bundle is shown in Figure 12. The bundle contains ‘sub-bundles’ known as collections which contain:

- Data Products
- Browse
- Calibration
- Documents
- Ancillary.

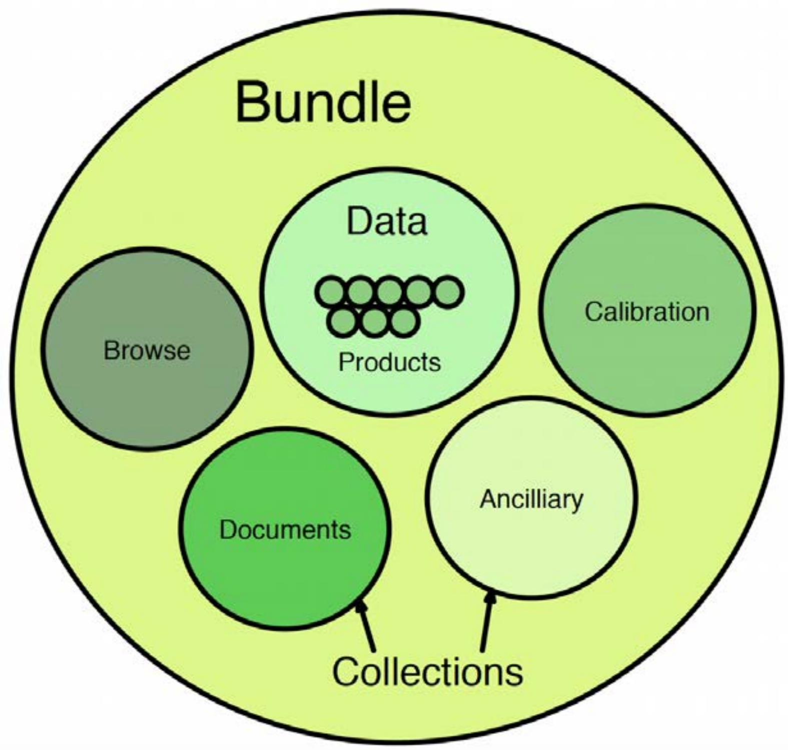

Figure 12 ExoMars bundle example. Credit ESA.

A CaSSIS bundle has yet to be defined. It is proposed that CaSSIS has a single bundle which contains collections shown in Table 19.

Table 19 Proposed top level CaSSIS bundle contents

Bundle Title	Collection	Description
CaSSIS top level bundle	Data Products	Contains all non-browse delivered data to the PSA generated by Uni Bern for entire mission. Described in Section 6.2.
	Browse	Contains stitched browse products of calibrated datasets generated by Uni Bern for entire mission (Section 6.2.4).
	Calibration	Contains calibration products used in the calibration of data products.
	Documents	Contains all CaSSIS documents which are archived in the PSA, see

		list of documents section.
	Ancillary	Not needed

6.3.1 CaSSIS Bundle Collection: Data Products

The data products collection will contain all non-browse data products delivered to the PSA by the University of Bern. These products are described in Section 6.2. See Section 5.7 and 5.8 for examples of XML headers of the calibrated and geometry data respectively.

6.3.2 CaSSIS Bundle Collection: Browse

The browse collection will contain all browse products of the calibrated data delivered to the PSA by the University of Bern. These products are described in Section 6.2

6.3.3 CaSSIS Bundle Collection: Calibration

The calibration collection contains all the calibration products used for the calibration of data products, overviewed in Section 2.4.9. Xml header files are currently not produced for these products. However, they will be produced by the University of Bern on a TBD timescale.

6.3.4 CaSSIS Bundle Collection: Documents

The documents collection will contain all of the CaSSIS related documents that will be archived to the PSA. These documents are listed in the List of Documents table at the beginning of this document. **Corresponding XML label files for each of these documents are TBD.**

6.3.5 CaSSIS Bundle Collection: Ancillary

CaSSIS data does not need to use an ancillary collection.

6.4 Data delivery to the PSA schedule

Deliverables	Schedule	Reference	Comment	Status
Commissioning (COM) (April-June 2016)				
Level 0 (raw)	January 2018		With CaSSIS xml headers	Delivered
Level 1 (calibrated)	January 2018		With CaSSIS xml headers	Delivered

Mars Capture Orbit (MCO) (November 2016 - March 2017)				
Level 0 (raw)	January 2018		With CaSSIS xml headers	Delivered
Level 0 (FSW corrected, partially processed)	January 2018		FSW errors in raw data assemblage corrected manually for observations of Mars. No corrections for star data.	Delivered
Level 1 (partially processed)	January 2018		With CaSSIS xml headers	Delivered
FSW Test (FSW) and In-orbit Commissioning (IOC) (March 2018-May 2018)				
Level 0 (raw)	August 2019			
Level 1 (partially processed)	August 2019			
MTP 1-2 (May 2018-June 2018)				
Level 0 (raw)	August 2019			
Level 1 (calibrated)	August 2019			
Level 3	October 2019			
MTP 3-4 (July 2018-August 2018)				
Level 0 (raw)	November 2019			
Level 1 (calibrated)	November 2019			
Level 3	February 2020			
MTPnn (nn > 4)				
Level 0	Exec. +6 months			
Level 1	Exec. +6 months			
Level 3	Exec. +8 months			
Calibration Products				
Bias field	TBD			

Flat field	TBD			
Bad pixel map	TBD			
Straylight pattern	TBD			

6.5 Publically accessible data

All the data that is produced by the CaSSIS team is archived at the University of Bern. All this data is planned to be made available to the public, directly through the University of Bern. The timeline for publically accessible data is TBD and is dependent on the progress of required infrastructure (websites etc.).

7 REFERENCES

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