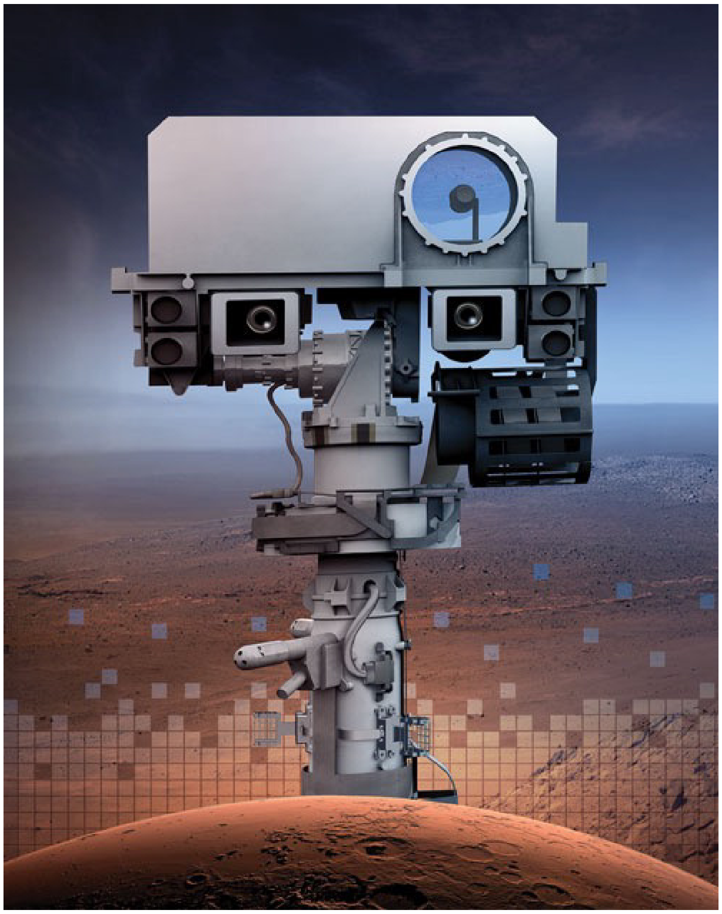

MARS2020 Software Interface Specification Planetary Instrument for X-ray Lithochemistry (PIXL) Reduced Data Products

Prepared by:
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JPL D-105236
Version 1.7.8

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SIGNATURES

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CHANGE LOG

DATE	SECTIONS CHANGED	REASON FOR CHANGE	REVISION
2020/04/24	All	• Initial draft	Draft v0.1
2020/05/14	All	• Addition of examples for RDRs, separate discussion of non-archived products, update to Appendix A for Labels of archived products	Draft v0.2
2020/05/26	All	• Incorporate Tim's feedback	Draft v0.3
2020/06/24	All	• Incorporate Kyle's feedback and enhancements to product descriptions • Pull in revised product snippets, labels	Draft v0.4
2020/07/24	All	• Incorporate Payam's feedback	Draft v0.5
2020/08/31	All	• Prep for initial external review	v0.9
2020/09/21	All	• Incorporate feedback from final internal review prior to external review • Updates to RBQ, RCS product specifications	v0.9.1
2020/09/28	5.2.4	• Remove discussion re MSA which will not archived. Notes: Initial draft revision submitted for URS review/approval	v1.0
2020/11/18	3 5.2.4 5.2.6	• Updates to the processing pipeline • Updated channel name columns in header for RFS Product • Revised snippets for RPM product to reflect correct datatypes (all pseudointensity values as floats)	v1.1
2020/12/03	5.2.1	• Complete description for MCC Context Images	v1.2
2021/01/04	5, Appendix A	• Updates to product snippets and labels • Addition of R08 product definition and label	v1.3
2021/01/22	5.3.1, 5.3.2 5, Appendix A	• Correct detector resolution value • Updated to product snippets and labels	v1.4
2021/02/04		• Incorporated comments from: Susie on PDS-related sections&references, Kyle & Bob Deen on LED state and illumination.	V1.6
2021/04/05	-	• Incorporated feedbacks from the peer review	V1.7
2021/04/15	Glossary	• Added RTT, changed figure 11,	V1.7.1
2021/05/19	All	• Incorporated comments from Kyle, Tim and Rob • Changed custodianship from P. Zamani to K. Uckert	V1.7.3

		• 5.2.2, channel index starts at 0, not 1. • Added “GV” to list of acronyms •	
2021/05/26	Cover Page	• Removed PIXL IS as a signatory	V1.7.4
20201/06/15	5.2.3, 5.3.1, Appendix B	• Changed relative error to absolute error in PIQUANT result products • Resolved TBD items in Appendix B	V1.7.5
2021/07/29	Appendix A, Appendix B, Acknowledgements, 5.3.2, 5.2.6	• Removed Appendix A and B • Added acknowledgements • Updated copyright test • Addressed remaining peer review liens	V1.7.6
2021/08/03	5.1.1	• Removed mention of deprecated RCI product	V1.7.7
2022/10/25	1.3, Table 4, 5.3.2	• Added description of Rock Component Sum products: RQA, RQB, RQC (previous RCS). • Added additional references to Section 1.3	V1.7.8
2023/02/26	Table 4, 5.3.2	• Modified RCA, RCB, RCC (previously RQA, RQB, RQC) product descriptions	V1.7.9

JPL URS301588

TBD ITEMS

SECTION	DESCRIPTION
All	Identified by red text
All	Questions about the document, to be resolved, are shown in { braces }

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ACRONYMS AND ABBREVIATIONS

APPS	AMMOS PDS Pipeline Service
ASCII	American Standard Code for Information Interchange
CODMAC	Committee on Data Management and Computation
DAWG	Data Archive Working Group
DEM	Digital Elevation Model
DPO	Data Product Object
EDR	Experiment Data Record
FEI	File Exchange Interface
FLI	Flood Light Illuminator
FSW	Flight Software
GDS	Ground Data System
GV (GV space)	Global Variable Memory in PIXL flight software
HK	House Keeping (record type)
ICD	Interface Control Document
IDPH	Instrument Data Product Header
IDS	Instrument Data System (part of mission GDS)
iFSW	Instrument Flight Software
iSDS	Instrument Science Data System
ISO	International Standards Organization
JPL	Jet Propulsion Laboratory
KB	Kilobytes
LSB	Least Significant Byte
M2020	Mars 2020
MB	Megabytes
MCC	Micro-Context Camera
MIPL	Multimission Image Processing Laboratory
MSA	Microscopy Society of America (digital spectra data format standard)
MSB	Most Significant Byte
NASA	National Aeronautics and Space Administration
ODL	Object Description Language
ODS	Operations Data Store
PDS	Planetary Data System

PIXL	Planetary Instrument for X-ray Lithochemistry
PMC	PIXL Motion Counter
PSDD	Planetary Science Data Dictionary
RA	Robotic Arm
RAM	Random Access Memory
RCE	Rover Compute Element
RDR	Reduced Data Record
RTT	Round Trip Tracking token
SHERLOC	Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals
SIS	Software Interface Specification
TBD	To Be Determined
TC	Temperature Compensation
URL	Universal Resource Locator
VICAR	Video Communications and Retrieval
XRF	X-ray Fluorescence

GLOSSARY

TERM	DEFINITION
metadata	Selected or summary information about data. PDS catalog objects and data product labels are forms of metadata for summarizing important aspects of data sets and data products.
Round Trip Tracking (RTT)	Round Trip Tracking (RTT) token is a unique integer that is given to the PIXL instrument by the rover at the time a new command sequence is sent to the instrument. The PIXL iFSW subsequently tags all the products generated from that point on with that RTT. The RTT is used by the ground system to find find and associate some ancillary information about the PIXL observation with the given RTT which are not available from the PIXL instrument, such as the pose/location of the rover's arm.

1. INTRODUCTION

1.1 Purpose and Scope

The purpose of this data product Software Interface Specification (SIS) is to provide users of the Planetary Instrument for X-ray Lithochemistry (PIXL) Reduced Data Records (RDRs) with a detailed description of the product and a description of how they were generated, including data sources and destinations. PIXL will acquire high spatial resolution observations of rock and soil chemistry using micro X-ray fluorescence (XRF). Over a period of several hours, PIXL can autonomously raster-scan an area of the rock surface and acquire a hyperspectral map comprised of several thousand individual measured points. When correlated to a visual image acquired by PIXL's camera, these maps reveal the distribution and abundance variations of chemical elements making up the rock, tied accurately to the physical texture and structure of the rock, at a scale comparable to a 10X magnifying geological hand lens.

This SIS is intended to provide enough information to enable users to understand the PIXL RDR data products. The users for whom this SIS is intended are software developers of the programs used in generating the RDR products and scientists who will analyze the data, including those associated with the Mars 2020 (M2020) Project and those in the general planetary science community.

This SIS is also the official reference for defining the higher level PIXL products which will be archived at the PDS geosciences node. Note that some RDRs that are not used for science analysis may not appear in the PDS archives, i.e. “PNG” images.

1.2 Contents

This data product SIS describes how the M2020 PIXL instrument acquires its data, and how the data products are organized, formatted, labeled, and uniquely identified. The document discusses standards used in generating the product and software that may be used to access the product. The data product structure and organization are described in sufficient detail to enable a user to read the product. Finally, examples of a product labels are provided.

1.3 Applicable Documents and Constraints

This data product SIS is responsive to the following M2020 documents:

1. Mars 2020 Software Interface Specification Camera Instrument Data Products, JPL D-99960, December 21, 2020.

2. Mars 2020 (M2020) Software Interface Specification: PIXL Instrument Experiment Data Record (EDR) Data Products for Non-Imaging Components, JPL D-99963, January 29, 2021.

3. Mars 2020 PIXL PDS Archive Bundle Software Interface Specification (SIS), Version 1.0, February 4, 2021.

4. Allwood, Wade, Clark, Elam, Flannery, Foote, Hurowitz, Knowles. Texture-specific elemental analysis of rocks and soils with PIXL: The Planetary Instrument for X-ray Lithochemistry on Mars 2020, *IEE Aerospace Conference Proceedings*, June 2015,
DOI: 10.1109/AERO.2015.7119099. *IEEE Aerospace Conference Proceedings*, June 2015,
DOI: 10.1109/AERO.2015.7119099

5. PIXL Command & Telemetry Dictionary, JPL Document D-94125, M2020 DRD MO-001-01C

6. Allwood AC, Wade LA, Foote MC, Elam WT, Hurowitz JA, Battel S, Dawson DE, Denise RW, Ek EM, Gilbert MS, King ME. PIXL: Planetary instrument for X-ray lithochemistry. *Space Science Reviews.* 2020 Dec;216(8):1-32.
DOI: 10.1007/s11214-020-00767-7

7. W.T. Elam, C.M. Heirwegh (2022), PIQUANT Piquant (Version v3.2.11) [Computer software]. Zenodo.
DOI: 10.5281/zenodo.6959125

8. PIXLISE:

   a) P. Nemere, T. Barber, A. Galvin, A.P. Wright, S.M. Fedell, R. Stonebraker, J. Corkins, S. Davidoff (2022), PIXLISE Core (Version v2.0) [Computer software]. *Zenodo*.
   DOI: 10.5281/zenodo.6959096

   b) P. Nemere, T. Barber, A. Galvin, A.P. Wright, S.M. Fedell, R. Stonebraker, J. Corkins, S. Davidoff (2022), PIXLISE UI (Version v2.0) [Computer software]. *Zenodo*.
   DOI: 10.5281/zenodo.6959109

   c) A.P. Wright, P. Nemere, A. Galvin, S. Davidoff (2022), PIXLISE Diffraction Detection (Version v2.0) [Computer software]. *Zenodo*.
   DOI: 10.5281/zenodo.6959138

   d) P. Nemere, T. Barber, A. Galvin, A.P. Wright, S.M. Fedell, R.. Stonebraker, J. Corkins, S. Davidoff (2022), PIXLISE Data Formats (Version v2.0) [Computer software]. *Zenodo*.
   DOI: 10.5281/zenodo.6959146

This SIS is also consistent with the following Planetary Data System documents, relating to PDS Standards Version 4 (PDS4). These documents are subject to periodic revision. The most recent versions may be found by following the hyperlinks below. The PDS4 products specified in this SIS have been designed based on the versions current at the time, which are those listed below. Data products will be archived using the version of the PDS Information Model that is current at the time the products have passed peer review. Peer-reviewed products do not need to be revised to incorporate subsequent changes in the Information Model.

4. Planetary Data System Standards Reference, version 1.15.0.0, October 20, 2020, https://pds.nasa.gov/datastandards/documents/sr/.

5. Planetary Data System Data Provider's Handbook, version 1.15.0.0, October 2, 2020, https://pds.nasa.gov/datastandards/documents/dph/.

6. PDS4 Common Data Dictionary, Abridged, version 1.15.0.0, December 23, 2020, https://pds.nasa.gov/datastandards/documents/dd/.

7. PDS4 Information Model Specification, version 1.15.0.0, December 23, 2020, https://pds.nasa.gov/datastandards/documents/im/.

Finally, this SIS is meant to be consistent with the contract negotiated between the M2020 Project and the PIXL Principal Investigator (PI) in which experiment data records and documentation are explicitly defined as deliverable products.

1.4 **Relationships with Other Interfaces**

Changes to this PIXL RDR SIS document affect the products, software, and/or documents listed in Table 1.

Name	Type P=product S=software D=document	Owner
PIXLISE	S	JPL Section 397
PIXL PDS-RAW	P	IDS
NAIF/SPICE	P,S	NAIF
PXIL Quicklook products	P, S	PIXL
Jupyter Notebook	S	PIXL

Table 1 - Product and Software Interfaces to this SIS

2. PIXL INSTRUMENT OVERVIEW

PIXL (Planetary Instrument for X-ray Lithochemistry) is a microfocus X-ray fluorescence instrument that measures elemental chemistry at sub-millimeter scales. This is achieved by focusing an X-ray beam to a small spot ~ 150 μm, scanning the surface with this beam, and then measuring the induced X-ray fluorescence. Since PIXL also contains a micro-context camera (MCC) it correlates sub-mm scale geochemistry with surface texture.

PIXL is mounted on the rover's robotic arm, allowing it to be placed in close proximity to the surface of selected science targets. For additional precision in placement, and to correct for drift in the robotic arm positioning, PIXL's mounting to the arm includes an articulated hexapod system, allowing PIXL's position in space to be finely adjusted.

In addition to the PIXL Sensor Assembly mounted on the robotic arm, the instrument includes its own electronics system with an instrument computer and memory module, mounted inside the rover body. PIXL is also furnished with a calibration target, mounted externally to the rover in reach of the arm.

PIXL observations consist of a suite of X-ray fluorescence measurements, context images, and metadata. The XRF measurements can be executed in a variety of geometries depending on target type and available observation time, and are accompanied by a set of images documenting the target and its position relative to the instrument.

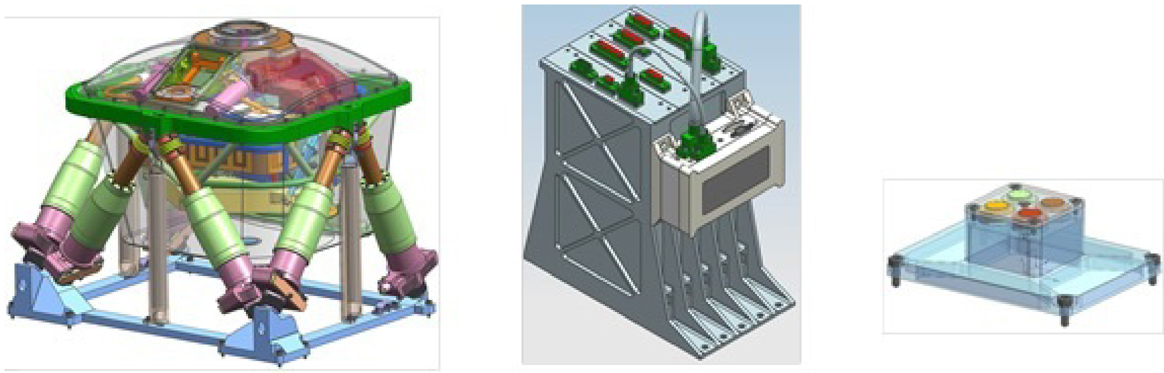


Figure 1 - PIXL Hardware
PIXL is comprised of three primary components: the sensor assembly is mounted on the rover arm, the electronics which control the sensor is mounted within the rover body, and the calibration target mounted externally within arm's reach on the rover arm.

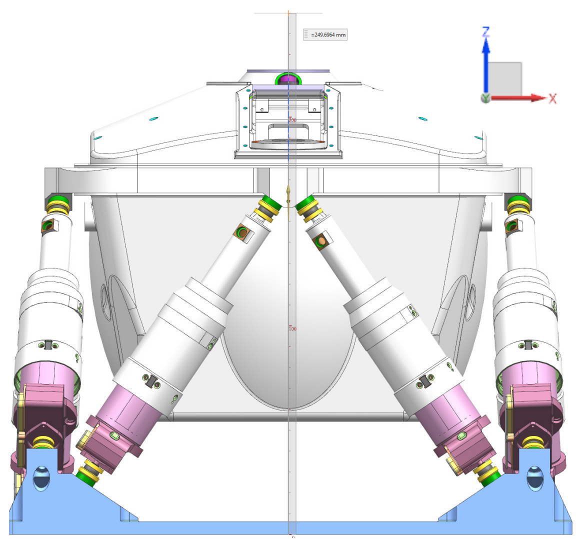


Figure 2 - The Sensor Assembly
Showing 4 of the 6 the articulation sliders (not pictured are those which oppose the sliders at far left and far right). At upper right are the definitions of the x, y and z axes.

The PIXL Electronics Box is located inside the Rover on the RAMP, the PIXL Sensor Assembly is located on the Rover Turret, and the PIXL Calibration Target is located on the robotic arm (RA) shoulder azimuth joint. See **Figure 3**, **Figure 4** and **Figure 10** for the approximate locations.

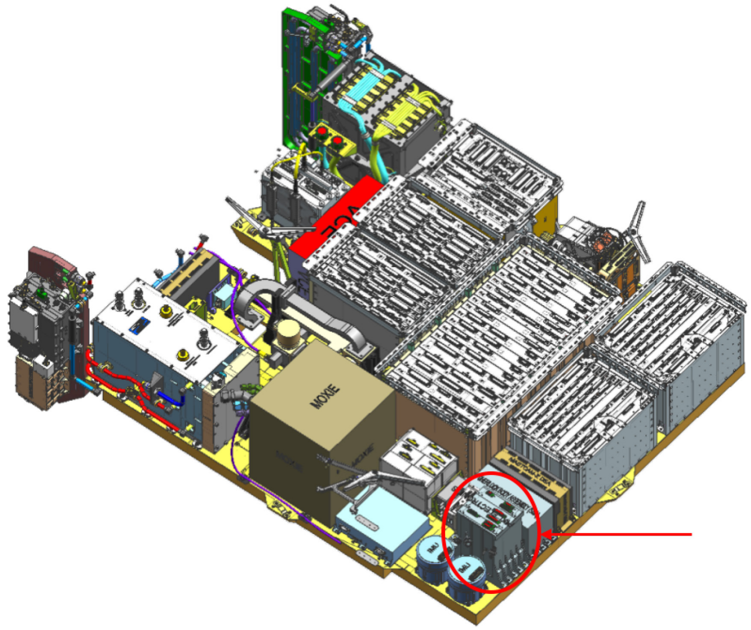


Figure 3 - PIXL Electronics location on the RAMP
The electronics consists of an instrument computer and memory module, mounted inside the rover body.

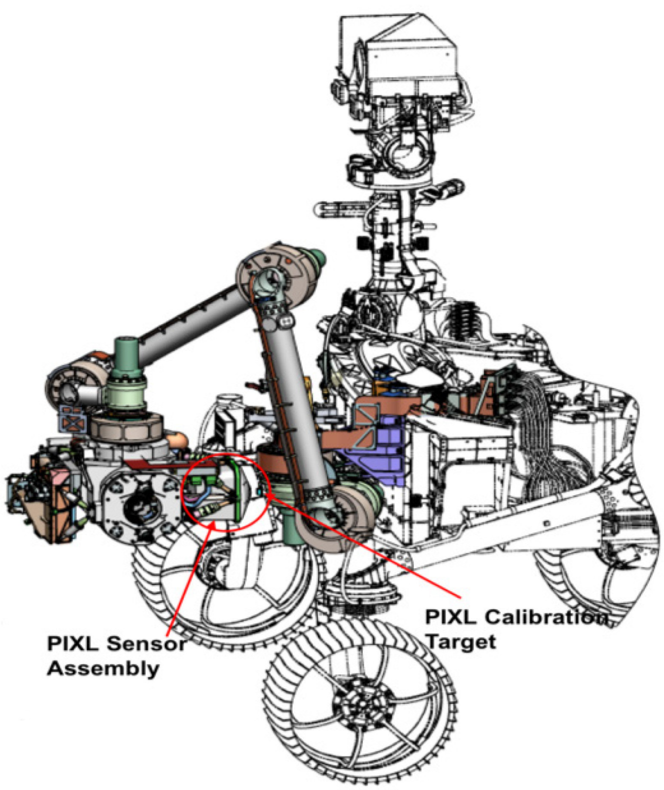


Figure 4 - PIXL Sensor Assembly and Calibration Target locations on the robotic arm

2.1 **PIXL Sensor Assembly**

The PIXL Sensor Assembly houses the primary sensors, detectors and X-ray source used for PIXL science measurements. Specifically, the Sensor Assembly houses the 28 kV High Voltage Power Supply (HVPS) which contains both a High Voltage Multiplier Module (HVMM) and a Low Voltage Control Module (LVCM). This system energizes the X-ray tube which focuses the resultant X-rays through the X-ray optic and onto the target surface. Two Silicon Drift Detectors (SDD) collect the X-rays fluoresced from the target, enabling chemical analysis of the surface. A key metric for interpreting fluoresced flux and focusing the X-ray spot onto the surface is a distance measurement to the surface. The PIXL Optical Fiducial system (OFS) enables the measurement of surface distance. This system utilizes a coarse and fine structured light illuminator (SLI), which is a device that shines laser spots onto the target in a specific pattern (coarse or fine). A high resolution black and white camera - the micro context camera (MCC) - is then used to take a picture of the surface with the laser pattern illuminating the surface. The PIXL Instrument Flight Software (iFSW) uses this information to determine the distance to the target surface at the location of the X-ray spot. The sensor head is mounted onto the turret with isolation struts and 6 active struts that provide x, y, and z motion completing the sensor assembly (sensor head + active hexapod). The active hexapod is driven by the needs to: scan the surface for a map, correct for any placement errors or drift errors from the Robotic Arm, and to focus the X-ray spot on the surface based on the distance to the target. The sensor assembly also has a dust cover that is controlled with a motor very similar to the motor used in the active struts (just smaller).

PIXL has a set of heaters on the Sensor Assembly. The survival heaters continually cycle to keep the HVMM within its required temperature limits. These heaters are on two circuits, and one is always asserted on. One is primary, and one is redundant. A PIXL temperature control board is used to cycle the heaters and, as a fall back, the heaters are controlled with mechanical thermostats. Other heaters for pre-warming the LVCM and the AFE are activated to bring the devices up into operational AFT limits.

PIXL's robust science operations are enabled by the PIXL iFSW. The PIXL iFSW controls all mapping, imaging, hexapod movement - basically all PIXL functions. So, the computing for PIXL operations is performed internally by PIXL, and the rover FSW will essentially send pass through commands with arguments that define what the PIXL iFSW will do.

2.2 **The PIXL Optical Fiducial System (OFS)**

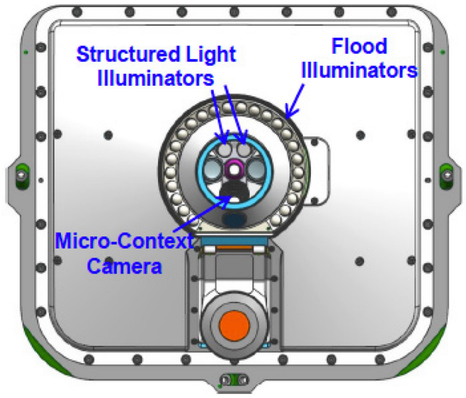


Figure 5 - The location of the OFS components in the head of the PIXL Sensor Assembly.

To ensure the measured chemistry is unambiguously tied to the textural features in the targets, PIXL has an optical fiducial system (OFS) co-aligned with the X-ray beam (**Figure 6**). The OFS consists of a micro-context camera, multi-color flood illuminator, and an LED illuminator that projects reference spots onto the target. The arrangement of color LEDs in the flood illuminator are shown in **Figure 7**. Together these are used to acquire visible images of the sample and enable visual registration of the position of the X-ray beam. The Micro-Context Camera has a spatial resolution of 50 μm per pixel and a field of view of 29 x 36 mm. This allows observations of textural features and microstructures as small as PIXL's X-ray beam, across an area of similar size to an abraded patch produced by the surface preparation tool on the rover. While an image is being taken, an array of light spots will be projected onto the sample surface. The spot array has a fixed geometric relationship to the X-ray beam to provide a means of spatially correlating measured chemistry to observed visual features as well as making a map of the rock topography.

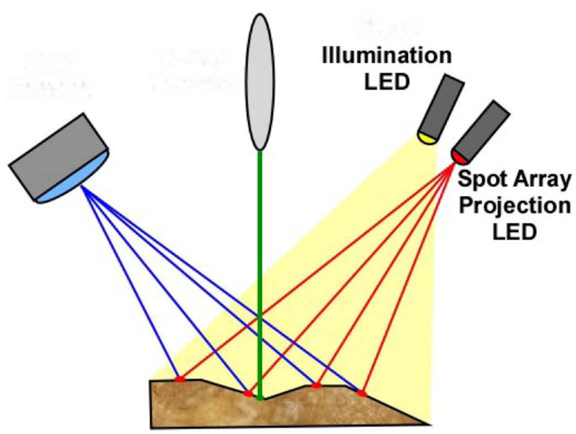


Figure 6 - Alignment of the OFS (the MCC in blue, Spot LED in red) with the PIXL X-ray beam (in green).

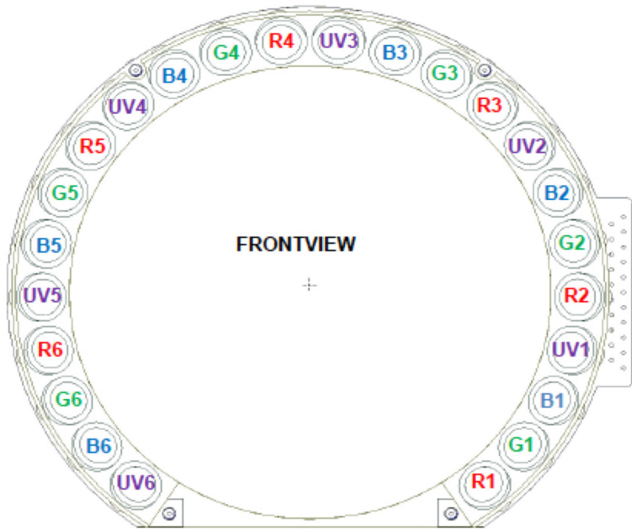


Figure 7 – Color arrangement within the flood illuminator

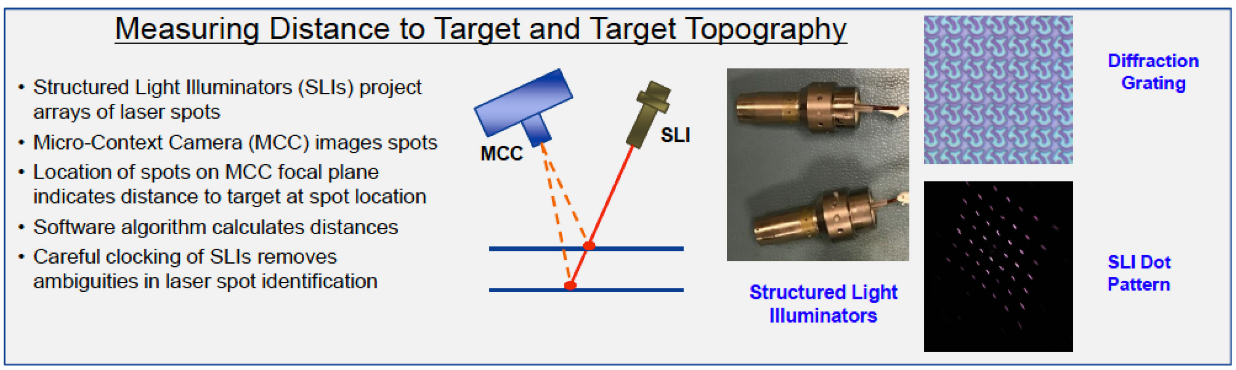


Figure 8 - Overview of the OFS process to determine target distances/topography.

2.3 **PIXL Electronics**

The PIXL electronics contain 3 FPGAs and a LEON3 processor. While the RCE has the ability to send basic commands to PIXL by sending a limited number of pass-through commands to the FPGA (typically only in iFSW fault cases), nominally all commanding and functions will be controlled with PIXL via the iFSW and the FPGA. Therefore, RCE commanding is quite limited and straightforward. Most RCE commanding will be done using the SEND_DATA and ACQUIRE_DATA commands. Note that the MCC camera electronics are inside the Rover as well and mate directly to the PIXL Electronics. The algorithms for localization reside on the MCC electronics but interface back to the PIXL iFSW. PIXL generates a large amount of data during operations, and while not all of this data will get sent to the Rover and back to earth, it is all stored internally within PIXL. PIXL has 8GB of flash which is likely sufficient to store all observations for the life of the mission.

2.4 **PIXL Calibration Target**

The PIXL calibration target contains 4 samples that PIXL will scan approximately once a month to enable recognition and correction for contamination in the instrument (dust, outgassing of spacecraft materials, etc.), avoid misidentification of peaks due to energy shift in the spectrum, maintain quantitative accuracy, and check detectability and sensitivity. The samples are as follows (clockwise, starting from the lower left of **Figure 9**):

1. A Polytetrafluoroethylene (PTFE) disk to provide a blank specimen which can verify X-ray detectionr of trace elements. It also gives a broadband X-ray backscatter for verifying the stability of the X-ray source spectrum. If any changes occur, it will be used for tracking those changes as well as any effects of dust on the target.

2. A glass version of the United States Geological Survey (USGS) basaltic standard BHVO-2, which was specially-prepared by the USGS as a large glass piece by melting and then rapidly quenching powdered BHVO-2 in a platinum boat. BHVO-2 has a known signature of strong peaks typical of basaltic materials and, as a glass, it has excellent homogeneity and stability. Its peak signature provides a reliable energy calibration and the certified concentrations of major, minor, and trace elements provide the main basis for quantitative calibration.

3. A disk of the National Institute of Standards and Technology NIST-610 glass donated by Clay Davis at NIST from their collection. NIST-610 demonstrates strong signals from about 17 geologically important trace elements at concentrations near 400 parts per million. It also contains about 40 other trace elements whose concentrations are not certified but which can be used to verify detection.

4. The mineral scapolite, which was donated by G. Rossman of the California Institute of Technology and embedded in epoxy by the PIXL team. Scapolite demonstrates strong emissions of S and Cl, which are important elements on Mars and present only at trace concentrations in the above standards.

The target at center with a metal cross (a chromium wire in one axis and a nickel wire in the other axis, each 200 µm in width) is used to precisely locate the X-ray beam with respect to the camera. Lastly there is a pseudo-random distribution of 100 black dots against a light background, divided between two surfaces separated by 5 mm in depth. MCC images of these dots allow an accurate estimation of the PIXL sensor head position with respect to the calibration target for checking accuracy of distance measurements made by the SLIs. The target is a passive element that requires no heating.

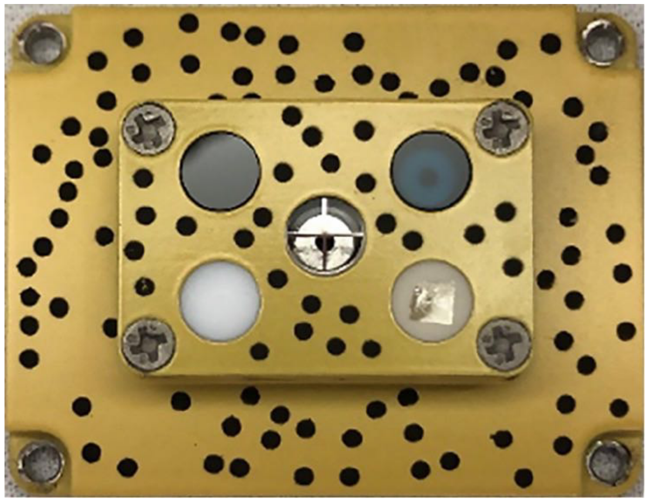


Figure 9 – The PIXL calibration target

The calibration target is located at the base of the Rover's arm turret, as shown in **Figure 10**.

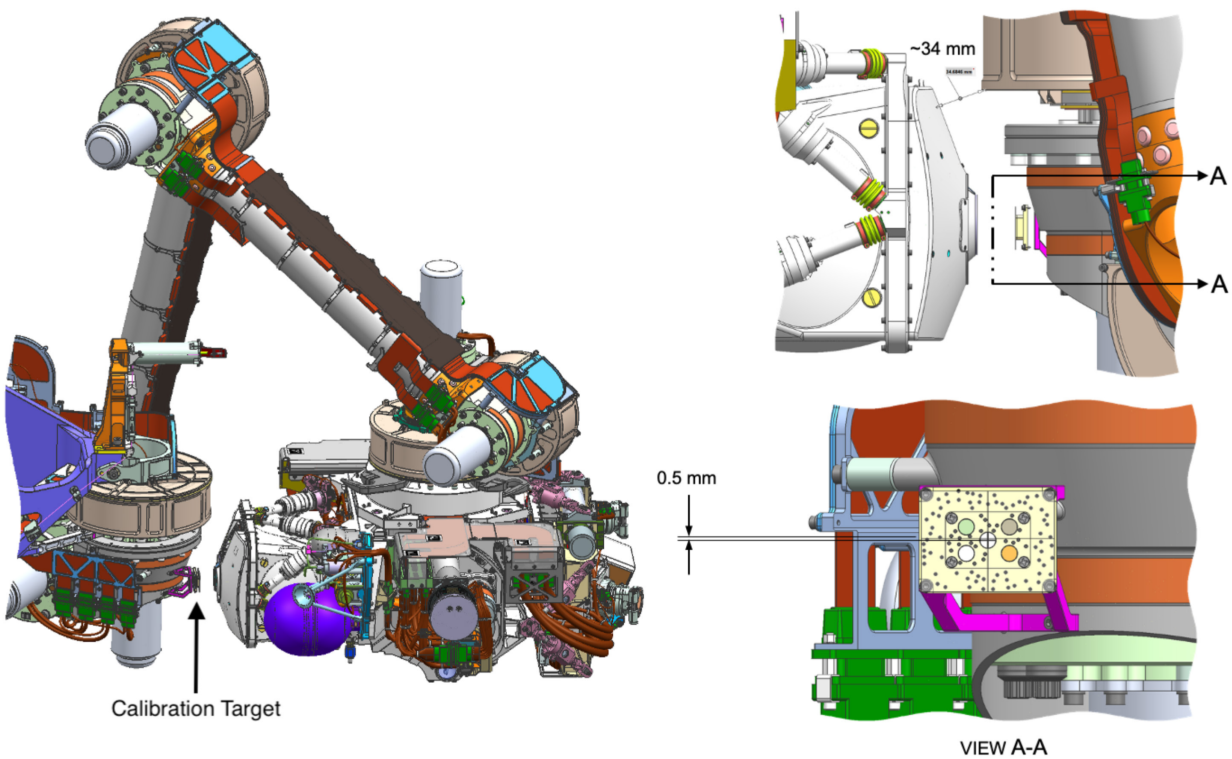


Figure 10 – The location of the PIXL calibration target

3. DATA PROCESSING OVERVIEW

PIXL data, as with all telemetry data that is downlinked from the Mars 2020 Rover, is acquired by the Deep Space Network (DSN) and processed by the Instrument Data System (IDS) into first order products. These products serve as initial inputs into processing steps in the Instrument

Science Data System (iSDS) pipelines to produce PDS-Partially-Processed and PDS-Calibrated products, as shown in **Figure 11** for the PIXL iSDS.

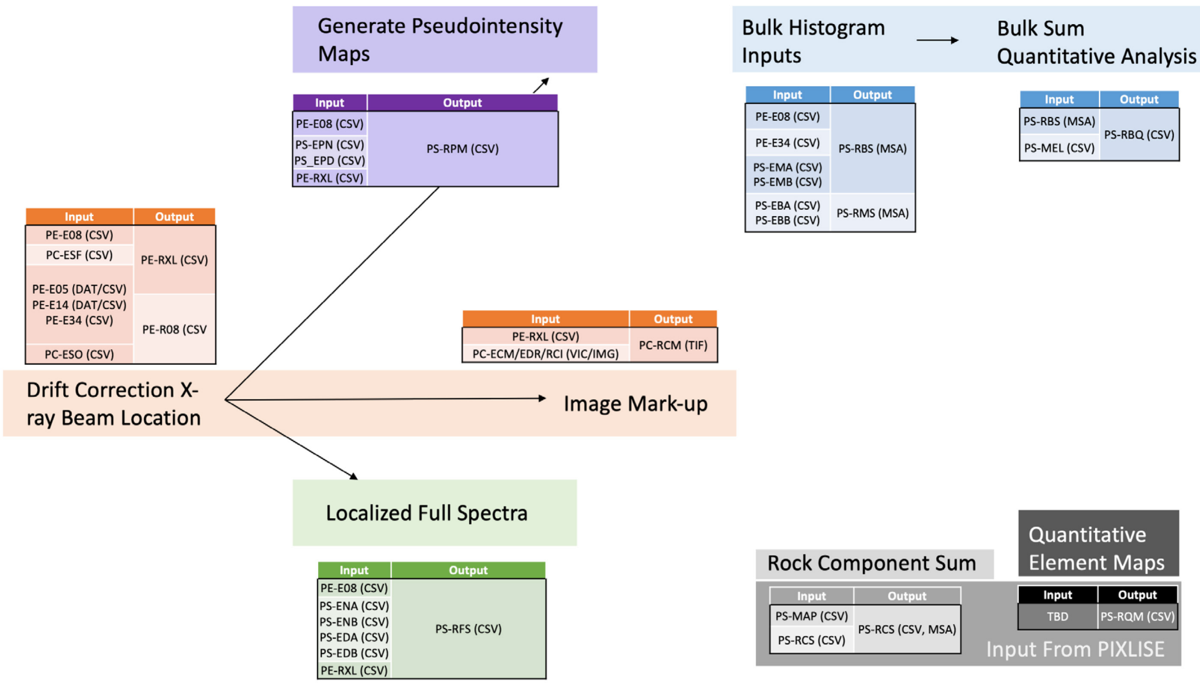


Figure 11 - The PIXL iSDS pipeline

3.1 **Data Processing Levels**

The table below relates PDS4 processing levels to their corresponding NASA terms. With the recent transition from PDS3 to PDS4, this SIS will utilize the PDS4 processing levels, and fall back to NASA levels as necessary to eliminate ambiguity. However, as it is a critical distinction not available in PDS4, the terms "EDR" (Experimental Data Record) and "RDR" (Reduced Data Record) will be used to provide the distinction between the products produced by the Mission SDS (mSDS) and the PIXL Instrument SDS (iSDS).

RDR data files are generated from "PDS-Raw", the telemetry packets within the project specific Standard Formatted Data Unit (SFDU) record.

PDS4	Description
Telemetry	Telemetry data stream as received at the ground station, with science and engineering data embedded.
PDS-Raw	Instrument science data (e.g., raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed.
PDS-Partially Processed	Level 0 data that have been located in space and may have been transformed (e.g., calibrated, rearranged) in a reversible manner and packaged with

PDS4	Description
	needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied).
PDS-Calibrated	Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength).
PDS-Derived	Geophysical parameters, generally derived from Level 1 data, and located in space and time commensurate with instrument location, pointing, and sampling.
	Geophysical parameters mapped onto uniform space-time grids.

Table 2 - Processing Levels for Science Data Sets

4. DATA PRODUCT OVERVIEW

4.1 File Naming Convention

The M2020 project has defined a product file naming convention that applies to all archivable products and instruments, across the project.

The file naming scheme has been relieved of the string length constraint imposed by the Level II 36.3 filename standard approved by PDS in 2009. PDS has migrated to a new standard that is PDS-4.

The primary attributes of the filename nomenclature are:

a) Uniqueness - It must be unique unto itself without the file system's directory path, across the entire mission, for the life of the mission. This protects against product overwrite as files are copied/moved within the file system and external to the file system, if managed correctly.
b) Metadata - It should be comprised of metadata fields that keep file bookkeeping and sorting intuitive to the human user. Even though autonomous file processing will be managed via databases, there will always be human-in-the-loop that puts a premium on filename intuition. Secondly, the metadata fields should be smartly selected based on their value to ground processing tools, as it is less CPU-intensive to extract information from the filename than from the label.

NOTE: Metadata information in the filename also resides in the product label.

The metadata fields have been selected based on MER and PHX lessons learned. In general, the metadata fields are arranged to achieve:

a) Sortability - At the beginning of the filename resides a primary time-oriented field such as Spacecraft Clock Start Count (SCLK). This allows for sorting of files on the M2020 file system by spacecraft data acquisition time as events occurred on Mars.

b) Readability - An effort is made to alternate Integer fields with ASCII character fields to optimize differentiation of field boundaries for the human user.

4.1.1 File Naming Convention for Higher Level Products (PDS-Process, PDS-Derived / RDRs)

Each PIXL RDR data product can be uniquely identified by incorporating into the product filename at minimum the Instrument ID, SCLK (or UTC), Product Type identifier, and Version number.

File names for higher level products follow the format provided in **Table 3** below. The header of this table provides an illustration of the overall convention.

1 2	3	4	5 6 7 8	9	10 11 12 13 14 15 16 17 18 19	20	21 22 23	24 25 26	27	28	29 30 31	32 33 34 35	36 37 38 39 40 41 42 43 44	45 46 47 48	49	50 51	52	53 54	55	56 57 58
INSTRUMENT	COLOR/FILTER	SPECIAL FLAG	PRIMARY TIMESTAMP	VENUE	SECONDARY TIMESTAMP	_	TERTIARY TIMESTAMP	PROD TYPE	GEOMETRY	THUMBNAIL	SITE	DRIVE	SEQUENCE/RTT	CAM SPECIFIC	DOWNSAMPLE	COMPRESSION	PRODUCER	VERSION	.	EXT

Field	Position (size, type [ascii/int])	Description
Instrument	01 (2, a)	Instrument identifier. PIXL imaging instrument identifier: • PC : PIXL Micro Context Cam (MCC) PIXL non-imaging instrument identifiers: • PE : PIXL Engineering • PS : PIXL Spectrometer Note: there are other instrument identifiers not associated with PIXL that have been omitted from this document.
Color/Filter	03 (1, i/a)	Color flag - see Section 2.2. For image RDRs only (otherwise it is set to '_' for N/A). The PIXL MCC captures only grayscale images. In the event of no LED illumination (see below), this flag is always set to 'M' for grayscale (Monochrome/Panchromatic). In the event of LED illumination, the flag is set based on the LEDs used to illuminate the target. LED Color / Flag: Red = R; Green = G; Blue = B; White (multiple) = W; UV = U

LED Color	Flag
Red	R
Green	G
Blue	B
White (multiple)	W
UV	U

1–2	INSTRUMENT
3	COLOR/FILTER
4	SPECIAL FLAG
5–8	PRIMARY TIMESTAMP
9	VENUE
10–19	SECONDARY TIMESTAMP
20	_
21–23	TERTIARY TIMESTAMP
24–26	PROD TYPE
27	GEOMETRY
28	THUMBNAIL
29–31	SITE
32–35	DRIVE
36–44	SEQUENCE/RTT
45–48	CAM SPECIFIC
49	DOWNSAMPLE
50–51	COMPRESSION
52	PRODUCER
53–54	VERSION
55	.
56–58	EXT

Field	Position (size, type [ascii/int])	Description
		<table><tr><td>SLI-A (Dense)</td><td>D</td></tr><tr><td>SLI-B (Sparse)</td><td>S</td></tr><tr><td>Off</td><td>_</td></tr><tr><td>Other</td><td>O</td></tr></table> Other color flags may be defined in the future.
Special flag	04 (1, a)	Special Processing flag. Applicable to image RDRs only, otherwise set to '_' for N/A. The special processing character is used to indicate off-nominal or special processing of the image. Examples include use of different correlation parameters, special stretches to eliminate shadows, reprocessing with different camera pointing, etc. The meaning of any individual character in this field (other than "_" which means nominal processing) will be defined on an ad-hoc basis as needed during the mission. Within one Sol or a range of sols, the character will be used consistently. So, this field can be used to group together all derived products resulting from one kind of special processing. An attempt will be made to maintain consistency across different sols as well, but this may not always be possible; thus the meaning of characters may change across different individual or ranges of sols. A database will be maintained containing all special processing designators that are used, the sols they relate to, and a description of the special processing that was done. This information will be included in the PDS archive.
Primary timestamp	05 (4, i/a)	The Primary timestamp of coarser granularity than the Secondary timestamp (documented later). Value type is based on either of four scenarios: <u>Flight Cruise</u> Year-DOY (4 alphanumeric) - This field stores two metadata items in the order: a) One alpha character in range "A-Z" to designate Earth Year portion of the UTC-like time value, representing Years 2017 to 2042 b) Three integers in range "001-366" representing Day-of-Year (DOY) <u>Flight Surface</u> Sol (4 integer) - This field stores the 4-integer Sol (Mars solar day) of the <u>first</u> (i.e., lowest Clock time) acquired instrument data.

1-2	3	4	5-8	9	10-19	20	21-23	24-26	27	28	29-31	32-35	36-44	45-48	49	50-51	52	53-54	55	56-58
INSTRUMENT	COLOR/FILTER	SPECIAL FLAG	PRIMARY TIMESTAMP	VENUE	SECONDARY TIMESTAMP	_	TERTIARY TIMESTAMP	PROD TYPE	GEOMETRY	THUMBNAIL	SITE	DRIVE	SEQUENCE/RTT	CAM SPECIFIC	DOWNSAMPLE	COMPRESSION	PRODUCER	VERSION	.	EXT

Field	Position (size, type [ascii/int])	Description

<u>Ground Test in which SCLK in NOT reset</u>

When SCLK continuously increments and does NOT repeat, there are two variants:

a) Year-DOY (4 alphanumeric) - This field stores two metadata items in the order:

   1. One alpha character in range "A-Z" to designate Earth Year portion of the UTC-like time value, representing Years 2017 to 2042
   2. Three integers in range "001-365" representing Day-of-Year (DOY)

– OR –

b) Sol (4 integer) - This field stores the 4-integer Sol (Mars solar day) of the <u>first</u> (i.e., lowest Clock time) acquired instrument data.

<u>Ground Test in which SCLK is reset</u>

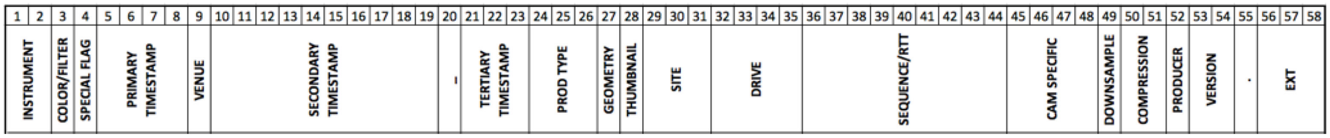
When SCLK is reset and repeats, we lose time "uniqueness". So, we have to change from SCLK to using "wall clock" derived from ERT and represent with a UTC-like format:

DOY-Year (4 alphanumeric) - This field stores two metadata items in reverse order compared to the previous "Year-DOY" cases, indicating that the Secondary Time field (described later) contains ERT

a) Three integers in range "001-365" representing Day-of-Year (DOY)
b) One alpha character in range "A-Z" to designate Earth Year portion of the UTC-like time value, representing Years 2017 to 2042

This field's value type (Sol or Year/DOY) dictates the value type for the Secondary time field (SCLK or UTC-like).

Scenario	Time Type	Value Format	Valid Values	Time Range
Flight Cruise	Year-DOY	A<ddd>, B<ddd>, . . . Z<ddd>	A001, A002, … A365, B001, B002, … B365, . . . Z001, Z002, …, Z365	2017 DOY 1 – 365, 2018 DOY 1 – 365, . . . 2042 DOY 1 – 365



Field	Position (size, type [ascii/int])	Description

		<aaaa>	"_ _ _ _" (4 underscores)	Value is out of range
Flight Surface	Sol	<nnnn>	0000, 0001, … 9999	0 thru 9999
		<aaaa>	"_ _ _ _" (4 underscores)	Value is out of range
Ground Test SCLK NOT reset	Year-DOY	(same as Flight Cruise)	(same as Flight Cruise)	(same as Flight Cruise)
	Sol	<nnnn>	"0000", "0001", … "9999"	0 thru 9999
		<aaaa>	"_ _ _ _" (4 underscores)	Value is out of range
Ground Test SCLK Reset	DOY-Year	<ddd>A, <ddd>B, . . . <ddd>Z	001A, 002A, … 365A, 001B, 002B, … 365B, . . . 001Z, 002Z, … 365Z	DOY 1 – 365 2017, DOY 1 – 365 2018, . . . DOY 1 – 365 2042
		<aaaa>	"_ _ _ _" (4 underscores)	Value is out of range

Venue	9 (1, a)	Mission venue identifier: • _: Flight (surface or cruise) • A: AVSTB • F: FSWTB • M: MSTB • R: "ROASTT" • S: "Scarecrow" • V: VSTB Non-flight venues were/are used for various ground activities and do not apply to flight data which are archived. Other venue identifiers may be defined later.
Secondary timestamp	10 (10, i)	Secondary timestamp of finer granularity than the Primary timestamp. Value type is based on either of four scenarios: <u>Flight Cruise</u> SCLK – This field stores the 10-integer SCLK (seconds). Which specific SCLK count (Start or End) is used depends on the instrument, but nominally it is the starting count of the <u>first</u> (i.e., lowest Clock time) acquired instrument data.

INSTRUMENT	COLOR/FILTER	SPECIAL FLAG	PRIMARY TIMESTAMP	VENUE	SECONDARY TIMESTAMP	_	TERTIARY TIMESTAMP	PROD TYPE	GEOMETRY	THUMBNAIL	SITE	DRIVE	SEQUENCE/RTT	CAM SPECIFIC	DOWNSAMPLE	COMPRESSION	PRODUCER	VERSION	.	EXT

Field	Position (size, type [ascii/int])	Description

Flight Surface

SCLK – Same as for "Flight Cruise"

Ground Test in which SCLK in NOT reset

SCLK – Same as for "Flight Cruise"

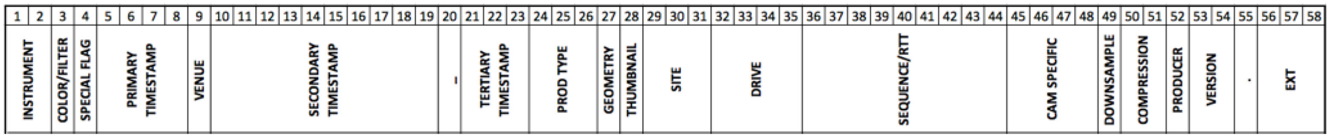
Ground Test in which SCLK is reset

ERT - This field stores the ERT time portions Month, Day-of-month, Hour and Seconds as 10 integers in a UTC-like format

This field's value type associates with the value type of the Primary timestamp field.

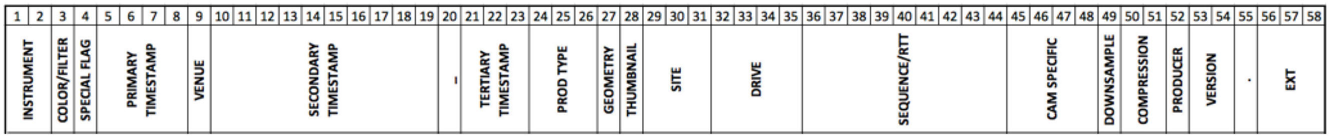
Scenario	Time Type	Value Format	Valid Values	Time Range
Flight Cruise	SCLK	<ssssssssss> (Seconds)	0000000000, 0000000001, • • • 9999999999	0 thru 9999999999
		<aaaaaaaaaa>	"__________" (10 underscores)	Value is out of range
Flight Surface	SCLK	(same as Flight Cruise)	(same as Flight Cruise)	(same as Flight Cruise)
Ground Test SCLK NOT reset	SCLK	(same as Flight Cruise)	(same as Flight Cruise)	(same as Flight Cruise)
Ground Test SCLK reset	ERT	<MMDDHHmmss> (Month, Day-of-month, Hour, Minute, Second)	"0101010000", "0101010001", • • • "1231235959"	January 1, 01:00:00 thru December 31, 23:59:59
		<aaaaaaaaaa>	"__________" (10 underscores)	Value is out of range

Field	Position (size, type [ascii/int])	Description
_	20 (1, a)	Underscore for readability. Always set to "_".



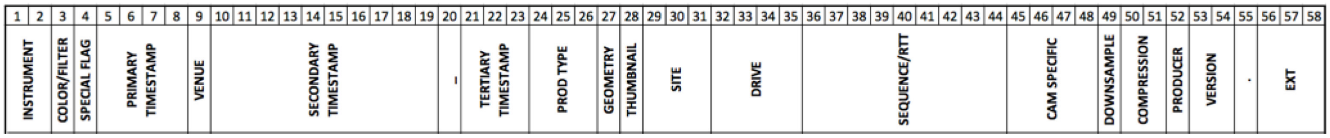
Field	Position (size, type [ascii/int])	Description
Milliseconds	21 (3, i)	Milliseconds of either the SCLK or UTC.
Product type	24 (3, a)	Product identifier. See **Table 4.**
Geometry	27 (1, a)	Linearization flag. Applicable to image RDRs only, otherwise it is set to '_' for N/A. • _ : Non-linearized (raw geometry) • L : Product has been linearized with nominal stereo partner • A : Product has been linearized with an actual stereo partner. Note that for the "A" case, an image can have multiple stereo partners and the linearized images will be different for each partner. A user will need to look in the ODL/VICAR label to determine which partner was used for linearization.
Thumbnail	28 (1, a)	Thumbnail flag. Applicable to image RDRs only, otherwise it is set to '_' for N/A. • T : Product is a thumbnail • N : Nominal Product is a non-thumbnail (full-frame, sub-frame, down-sample)
Site	29 (3, i/a)	Site identifier. See Section 6.1.7 on Site frames. Site location count from the RMC where the data was acquired.

Values	Range
000, 001, …, 999	0 thru 999
A00, A01, …, A99	1000 thru 1099
B00, B01, …, B99	1100 thru 1199
…	…
Z00, Z01, … Z99	3500 thru 3599
AA0, AA1, …, AA9	3600 thru 3609
AB0, AB1, …, AB9	3610 thru 3619
…	…
ZZ0, ZZ1, …, ZZ9	10350 thru 10359
AAA, AAB, …, AAZ	10360 thru 10385
ABA, ABB, …, ABZ	10386 thru 10411
…	…
ZZA, ZZB, …, ZZZ	27910 thru 27935



<table>
<tr><th>Field</th><th>Position (size, type [ascii/int])</th><th>Description</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td>0AA, 0AB, …, 0AZ</td><td>27936 thru 27961</td></tr>
<tr><td>0BA, 0BB, …, 0BZ</td><td>27962 thru 27987</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>7CA, 7CB, …, 7CZ</td><td>32720 thru 32745</td></tr>
<tr><td>7DA, 7DB, …, 7DV</td><td>32746 thru 32767</td></tr>
<tr><td>_ _ _</td><td>Value out of range</td></tr>
</table>
</td></tr>
<tr><td>Drive</td><td>32 (4, i/a)</td><td>Drive identifier.

Drive count (position within a Site location) from the RMC where the data was acquired.
<table>
<tr><th>Values</th><th>Range</th></tr>
<tr><td>0000, 0001, …, 9999</td><td>0 thru 9999</td></tr>
<tr><td>A000, A001, …, A999</td><td>10000 thru 10999</td></tr>
<tr><td>B000, B001, …, B999</td><td>11000 thru 11999</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>Z000, Z001, … Z999</td><td>35000 thru 35999</td></tr>
<tr><td>AA00, AA01, …, AA99</td><td>36000 thru 36099</td></tr>
<tr><td>AB00, AB01, …, AB99</td><td>36100 thru 36199</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>AZ00, AZ01, …, AZ99</td><td>38500 thru 38599</td></tr>
<tr><td>BA00, BA01, …, BA99</td><td>38600 thru 38699</td></tr>
<tr><td>BB00, BB01, …, BB99</td><td>38700 thru 38799</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>LJ00, LJ01, …, LJ35</td><td>65500 thru 65535</td></tr>
<tr><td>_ _ _ _</td><td>Value is out of range</td></tr>
</table>
</td></tr>
<tr><td>Seq-ID/RTT</td><td>36 (9, i/a)</td><td>Each PIXL activity is given a unique 9-digit token to distinguish it from other activities. This RTT is included in the filename of all EDR and RDR products to easily link images, spectra, and housekeeping files associated with a particular measurement.
Sequence-ID or Round-Trip Tracking token (RTT):</td></tr>
</table>



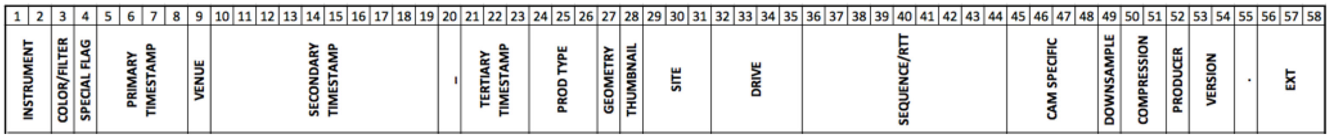
<table>
<tr><th>Field</th><th>Position (size, type [ascii/int])</th><th>Description</th></tr>
<tr><td></td><td></td><td>

Sequence-ID : Identifier indicating the command sequence the image was acquired from. Specific values will be assigned by the uplink team.
RTT : Unique identifier used for tracking activities. Used in the filename for PIXL ONLY.

Note: All cameras will have an RTT associated with their images but not included in the filename. PIXL is a special case where RTT and PMC are required for filename uniqueness.
</td></tr>
<tr><td>Camera specific</td><td>45 (4, i/a)</td><td>Camera specific identifier. Applicable to image RDRs only, otherwise it is set to ??? for N/A.
For the PIXL MCC, this field has the format ‘PPPP’ representing the PMC. Valid values are 0000-9999.</td></tr>
<tr><td>Downsample</td><td>49 (1, i/a)</td><td>Downsample resolution identifier. Applicable to image RDRs only, otherwise it is set to ‘_’ for N/A.

This value (n) indicates the level of downsampling applied to the image by the following equation:
$$\text{Resolution} = 2^n \times 2^n$$
<table>
<tr><th>Valid values</th><th>Resolution</th></tr>
<tr><td>0</td><td>1x1</td></tr>
<tr><td>1</td><td>2x2</td></tr>
<tr><td>2</td><td>4x4</td></tr>
<tr><td>3</td><td>8x8</td></tr>
<tr><td>…</td><td>…</td></tr>
</table>
</td></tr>
<tr><td>Compression</td><td>50 (2, i/a)</td><td>Compression type identifier. Applicable to image RDRs only, otherwise it is set to ??? for N/A.

There are several modes of compression available, varying per instrument. The uplink team will decide which algorithm will provide the best results on a per sequence basis.
<table>
<tr><th>Type</th><th>Valid values</th><th>Description</th></tr>
<tr><td>JPEG
(lossy)</td><td>00
01-99</td><td>Thumbnail
Jpeg quality level</td></tr>
</table>
</td></tr>
</table>



<table>
<tr><th>Field</th><th>Position (size, type [ascii/int])</th><th>Description</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td></td><td>A0</td><td>Jpeg quality level 100</td></tr>
<tr><td>ICER (lossy)</td><td>I1, I2, …, I8
I9</td><td>1 bpp, 2 bpp, …, 8 bpp
Anything higher than 8 bpp</td></tr>
<tr><td>Lossless</td><td>LI
LL
LM
LU</td><td>ICER
LOCO
Malin
Uncompressed</td></tr>
</table>
</td></tr>
<tr><td>Producer</td><td>52 (1, a)</td><td>Identifier for the institution/team that created this product:

J : JPL (for all PIXL products)
P : Principal investigator of instrument.

<table>
<tr><th>Instrument</th><th>PI</th></tr>
<tr><td>ECAM</td><td>JPL</td></tr>
<tr><td>MCZ</td><td>ASU (Tempe, AZ)</td></tr>
<tr><td>SCAM RMI</td><td>IRAP (France)</td></tr>
<tr><td>PIXL</td><td>JPL</td></tr>
<tr><td>SHERLOC</td><td>JPL</td></tr>
<tr><td>MEDA Skycam</td><td>Ministry of Education and Science (Spain)</td></tr>
<tr><td>EDL Cameras</td><td>JPL</td></tr>
<tr><td>HELI RTE/NAV</td><td>JPL</td></tr>
</table>

A – I, K – O, Q – Z : Co-I to be identified per instrument at the discretion of the instrument PI.
_ : undefined/other

Other producer codes will be added in the future.</td></tr>
<tr><td>Version</td><td>53 (2, a)</td><td>Product version number which increments by one whenever a previously generated file with an otherwise identical filename exists.
<table>
<tr><th>Values</th><th>Range</th></tr>
</table>
</td></tr>
</table>

Field	Positions
INSTRUMENT	1–2
COLOR/FILTER	3
SPECIAL FLAG	4
PRIMARY TIMESTAMP	5–8
VENUE	9
SECONDARY TIMESTAMP	10–19
_	20
TERTIARY TIMESTAMP	21–23
PROD TYPE	24–26
GEOMETRY	27
THUMBNAIL	28
SITE	29–31
DRIVE	32–35
SEQUENCE/RTT	36–44
CAM SPECIFIC	45–48
DOWNSAMPLE	49
COMPRESSION	50–51
PRODUCER	52
VERSION	53–54
.	55
EXT	56–58

<table>
<tr><th>Field</th><th>Position
(size, type [ascii/int])</th><th>Description</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td>01, 02 …, 99</td><td>1 thru 99</td></tr>
<tr><td>A0, A1, …, A9</td><td>100 thru 109</td></tr>
<tr><td>AA, AB, …, AZ</td><td>110 thru 135</td></tr>
<tr><td>B0, B1, B2 …, B9</td><td>136 thru 145</td></tr>
<tr><td>BA, BB, …, BZ</td><td>146 thru 171</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>Z0, Z1, …, Z9</td><td>1000 thru 1009</td></tr>
<tr><td>ZA, ZB, …, ZZ</td><td>1010 thru 1035</td></tr>
<tr><td>_ _</td><td>Value is out of range</td></tr>
</table>

Every version need not exist. E.g. version 01, 02, and 04 may exist but not 03. In general, the highest-numbered version represents the best version of that product. This field increments independently of all fields.</td></tr>
<tr><td>.</td><td>55 (1, a)</td><td>Separator for filename and extension. Always set to “.”</td></tr>
<tr><td>Extension</td><td>56 (3, a)</td><td>File extension
• CSV : comma separated file
• VIC: VICAR image file
• IMG: Same as VIC, but with an ODL label
• LBL: ODL Label file (not archived)
• PNG: PNG formatted image file (no label, not archived)
• TXT: ASCII text file
• XML: XML file, used for PDS4 Label Files (archived)
• MSA*: Microscopy Society of America spectral format file

Note: other file extensions to be added in the future</td></tr>
</table>

* *At the time of writing, inclusion of MSA files into the PDS archives were not deemed necessary and useful. However, they are included in this document for completeness.*

Table 3 - File Naming Fields

4.1.2 Product Identifiers & File Types

Product Identifier	Product Type	File Type(s)
RBQ	Histogram Bulk Quantitative Measurement	CSV, XML, LBL
RBS	Histogram Bulk Summed Spectrum A/B	MSA, XML, LBL
RCM	MCC Context Image w/ Mark-up	TIF, LBL, XML
RCA, RCB, RCC	Rock Component Sums	CSV, LBL, XML
RFS	Localized Full Spectra	CSV, LBL, XML
RMS	Histogram Bulk Max Value A/B	MSA, LBL, XML
RPM	PseudoIntensity Plots/Maps	CSV, LBL, XML
RXL	Drift Corrected X-ray Beam Locations	CSV, LBL, XML
R08	Engineering Value Housekeeping Frame	CSV, LBL, XML

Table 4 - Product Identifiers

5. DETAILED DATA PRODUCT SPECIFICATIONS

5.1 Partially Processed Data Products

5.1.1 Engineering Value Housekeeping Frame (R08)

Contains a subset of the PIXL housekeeping engineering and state-of-health (SOH) metadata, derived from the E08 Housekeeping Frame EDR. The R08 product presents the SOH data representing detector, chassis, and X-ray tube temperatures and voltages, among others, converted to physical units. Only SOH data associated with X-ray histogram or imaging activities are included in the product.

These products are in CSV (Comma Separated Values) format which can be loaded directly into Excel. The first row contains column headings and subsequence lines/rows have the actual values. This product is also defined in the PIXL non-imaging EDR SIS, section 4.2.5.

The engineering/housekeeping parameters are described in reference #5, PIXL *Command & Telemetry Dictionary* document.

Example Snippet from the engineering housekeeping product:

```
HK Frame
SCLK,PMC,RTT,hk_fcnt,u_hk_version,u_hk_time,u_hk_power,u_fsw_0,u_fsw_1,u_fsw_2,u_fsw
_3,u_fsw_4,u_fsw_5,f_pixl_analog_fpga_conv,f_pixl_chassis_top_conv,f_pixl_chassis_bo
ttom_conv,f_pixl_aft_low_cal_conv,f_pixl_aft_high_cal_conv,f_pixl_motor_v_plus_conv,
f_pixl_motor_v_minus_conv,f_pixl_sdd_1_conv,f_pixl_sdd_2_conv,f_pixl_3_3_volt_conv,f
_pixl_1_8_volt_conv,f_pixl_dspc_v_plus_conv,f_pixl_dspc_v_minus_conv,f_pixl_prt_curr
_conv,f_pixl_arm_resist_conv,f_head_sdd_1_conv,f_head_sdd_2_conv,f_head_afe_conv,f_h
ead_lvcm_conv,f_head_hvmm_conv,f_head_bipod1_conv,f_head_bipod2_conv,f_head_bipod3_c
onv,f_head_cover_conv,f_head_hop_conv,f_head_flie_conv,f_head_tec1_conv,f_head_tec2_
conv,f_head_xray_conv,f_head_yellow_piece_conv,f_head_mcc_conv,f_hvps_fvmon_conv,f_h
vps_fimon_conv,f_hvps_hvmon_conv,f_hvps_himon_conv,f_hvps_13v_plus_conv,f_hvps_13v_m
inus_conv,f_hvps_5v_plus_conv,f_hvps_lvcm_conv,i_valid_cmds_conv,i_crf_retry_conv,i_
sdf_retry_conv,i_rejected_cmds_conv,i_hk_side_conv,i_motor_1_conv,i_motor_2_conv,i_m
otor_3_conv,i_motor_4_conv,i_motor_5_conv,i_motor_6_conv,i_motor_cover_conv,i_hes_se
nse_conv,i_flash_status_conv
654665870,7,453,1211,0x190425E4,654665870,0x99800668,0xF80038EA,0x00238D00,0x0CD4003
1,0xC8000693,0x00084F2F,0x4AE4F2CA,34.5638,22.6331,24.6536,-41.8635,45.789,4.897,-
4.7469800000000015,-146.088,-146.5,3.225,1.769,8.886000000000003,-
8.81855,3.142,12.95,-24.9099,-
25.0322,23.6915,22.2482,21.1578,22.2482,22.1841,22.3765,21.3181,21.2861,22.152,22.40
86,23.1783,21.0937,21.3502,22.9538,3.9243,0.7277170000000001,30.8806,20.348,13.293,-
13.0879,4.98535,24.2021,53,0,0,0,0,1852,2217,2266,2124,2420,2437,864,1652,0
654665982,7,453,1247,0x190425E4,654665982,0x99800668,0xF80038EA,0x00238D00,0x0C04002
1,0x49000692,0x00084F2F,0x4AE4F2CA,36.1995,23.0821,25.1989,-41.8314,45.789,4.92,-
4.80665,-146.118,-146.515,3.22,1.769,8.886000000000003,-8.81573,3.142,12.94,-
29.9414,-
29.9683,24.6536,23.4028,20.7409,22.3124,22.3124,22.8897,21.222,21.3823,22.0237,24.23
67,24.4612,21.2861,22.2482,22.9218,3.92918,0.736264,30.8725,20.2991,13.293,-
13.1136,4.98535,24.6115,53,0,0,0,0,1852,2217,2266,2124,2420,2437,864,1652,0
654665982,7,453,1247,0x190425E4,654665982,0x99800668,0xF80038EA,0x00238D00,0x0C04002
1,0x49000692,0x00084F2F,0x4AE4F2CA,36.1995,23.0821,25.1989,-41.8314,45.789,4.92,-
4.80665,-146.118,-146.515,3.22,1.769,8.886000000000003,-8.81573,3.142,12.94,-
29.9414,-
29.9683,24.6536,23.4028,20.7409,22.3124,22.3124,22.8897,21.222,21.3823,22.0237,24.23
67,24.4612,21.2861,22.2482,22.9218,3.92918,0.736264,30.8725,20.2991,13.293,-
13.1136,4.98535,24.6115,53,0,0,0,0,1852,2217,2266,2124,2420,2437,864,1652,0
```

5.2 **Calibrated Data Products**

5.2.1 Drift Correction X-ray Beam Locations (RXL)

A CSV file containing a set of (x, y, z) positions in the PIXL base frame of each X-ray Beam location on the target surface and the corresponding location in the MCC image (as pixel coordinates), corrected for thermal drift of the robotic arm position or other unexpected motion. The columns of the data table are described below:

PMC (int): The PIXL Motion Counter is a counter representing a change to the PIXL Hexapod position. The counter starts at 0 when PIXL is powered on (presumably with the hexapod in the "homed" position) and increases by 1 each time the hexapod is moved.

x, y, z (double): The position of an X-ray beam location on the target, relative to the PIXL base frame.

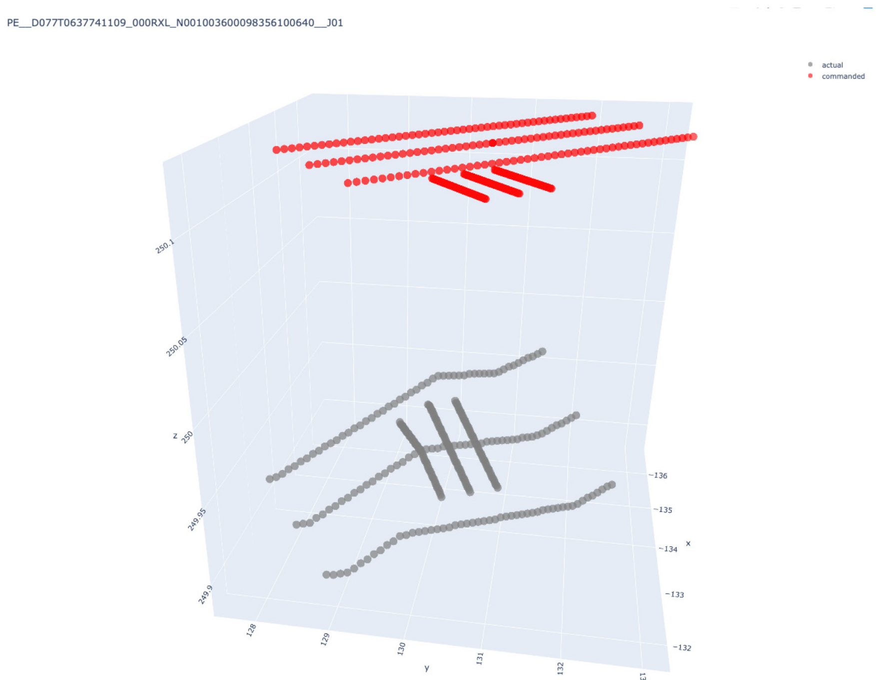
geometric_correction (double): A correction factor applied to the Beam Geometry Tool to account for the change in solid angle of the geometric quantification model when the target is not at the nominal distance.

PMC_####_MCC_i, PMC_####_MCC_j <where #### represents a PMC value> (string): The position (line: i and sample: j) of an X-ray beam location in a raw MCC image. *The origin of the image is located at the top left of the image.* The #### values in the column header represents the PMC of a specific MCC context image. Each MCC image collected during a scan has a unique PMC associated with it, and the X-ray beam locations within all images are calculated and reported in this RDR.

PMC_####_corr_i, PMC_####_corr_j <where #### represents a PMC value> (string): The position (line: i and sample: j) of an X-ray beam location in a distortion-corrected MCC image. *The origin of the image is located at the top left of the image*. The #### values in the column header represents the PMC of a specific MCC context image. Each MCC image collected during a scan has a unique PMC associated with it, and the X-ray beam locations within all images are calculated and reported in this RDR.

Example snippet:

```
PMC,x,y,z,geom_corr,PMC_0007_MCC_i,PMC_0007_MCC_j,PMC_0008_MCC_i,PMC_0008_MCC_j,PMC
_1691_MCC_i,PMC_1691_MCC_j,PMC_1692_MCC_i,PMC_1692_MCC_j
7,-
0.133551,0.134734,0.248100,1.000744,374.829742,273.244476,305.223846,290.380646,429
.190216,255.597290,360.359619,273.359131
8,-
0.136972,0.135651,0.248118,1.000625,443.567596,255.900436,374.829559,273.370728,497
.558533,237.915771,429.132080,256.134155
9,-
0.136909,0.135543,0.248128,1.000557,442.324066,258.050507,373.538727,275.528351,496
.343231,240.063156,427.881134,258.280884
10,-
0.136847,0.135435,0.248138,1.000490,441.099396,260.205322,372.266907,277.691040,495
.147491,242.214615,426.649323,260.432129
11,-
0.136784,0.135328,0.248147,1.000422,439.853760,262.354462,370.973511,279.848206,493
.931061,244.360550,425.396545,262.577698
12,-
0.136722,0.135219,0.248157,1.000354,438.627197,264.530121,369.698517,282.032837,492
.734253,246.532562,424.162445,264.750031
13,-
0.136660,0.135111,0.248167,1.000286,437.377747,266.690857,368.400848,284.202362,491
.514557,248.689499,422.905762,266.907654
```



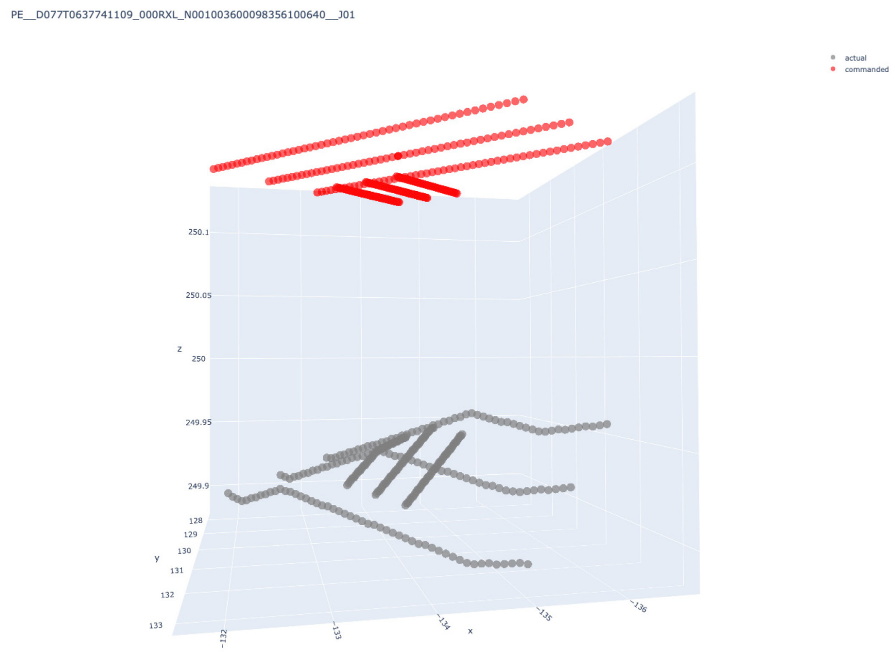


Figure 12 – Drift Corrected X-ray Beam Location images
Two alternative rotations of the same image are provided for clarity.

5.2.2 Histogram Bulk Max Value Spectrum (RMS)

An MSA file containing a header (denoted by a '#' at the start of each line) followed by a series of rows representing the energy-calibrated maximum value spectra.

Each row contains two integer values (comma-delimited), representing the maximum intensity at each channel for each detector. The maximum value is determined from all non-dwell histograms collected. Energy resolution and detector temperature are expected to be relatively constant for the duration of a map activity, and a characterization of energy resolution at each point is not necessary. The channel number corresponding to the maximum intensity for each detector is simply the row number of each entry (with the index starting at 0). The channel number may be converted to an energy value using the XPERCHAN and OFFSET values (of type double and double, respectively) present in the header:

energy (eV) = channel_number*XPERCHAN + OFFSET

The REALTIME (double) represents the total time that the spectrometer was acquiring an X-ray signal (live time + dead time), and is typically equivalent to the commanded integration time for a histogram

The LIVETIME (double) represents the total time that the spectrometer actually collected X-rays. This time will be less than the REALTIME due to brief pauses during acquisition from data transfer/readouts, resetting the preamplifier, and pulse pile-ups (overlapping pulses).

Example Snippet :

```
#FORMAT      : EMSA/MAS spectral data file
#VERSION     : TC202v2.0 PIXL
#TITLE       : BHVO Example, sum spectrum, Detector 0
#DATE        : 31-JAN-2017     Date in the format DD-MMM-YYYY, for example 07-JUL-
2010
#TIME        : 00:00           The time of day at which the spectrum was recorded,
in 24-hour format
#OWNER       : PIXL Flight Model       (PIXL will use this to indicate which
instrument took the data.)
#NPOINTS     : 4096     Number of data points in the spectrum (This can be zero for
configuration only files)
#NCOLUMNS    : 2     Number of data columns in the spectrum (This can be zero for
configuration only files)
#XUNITS      : eV
#YUNITS      : COUNTS
#DATATYPE    : YY
#XPERCHAN    : 8, 8   eV per channel (separate by commas if more than one detector)
#OFFSET      : 0, 0         eV of first channel  (separate by commas if more than
one detector
#SIGNALTYPE  : XRF
#YP_TEMP     : 32.537
#LIVETIME    : 9.931975999999999, 9.940800999999999   seconds (separate by commas if
more than one detector)
#REALTIME    : 10.0, 10.0   seconds (separate by commas if more than one detector)
#SPECTRUM    : start of spectrum data
0, 0
0, 0
0, 0
0, 0
0, 0
0, 0
0, 0
```

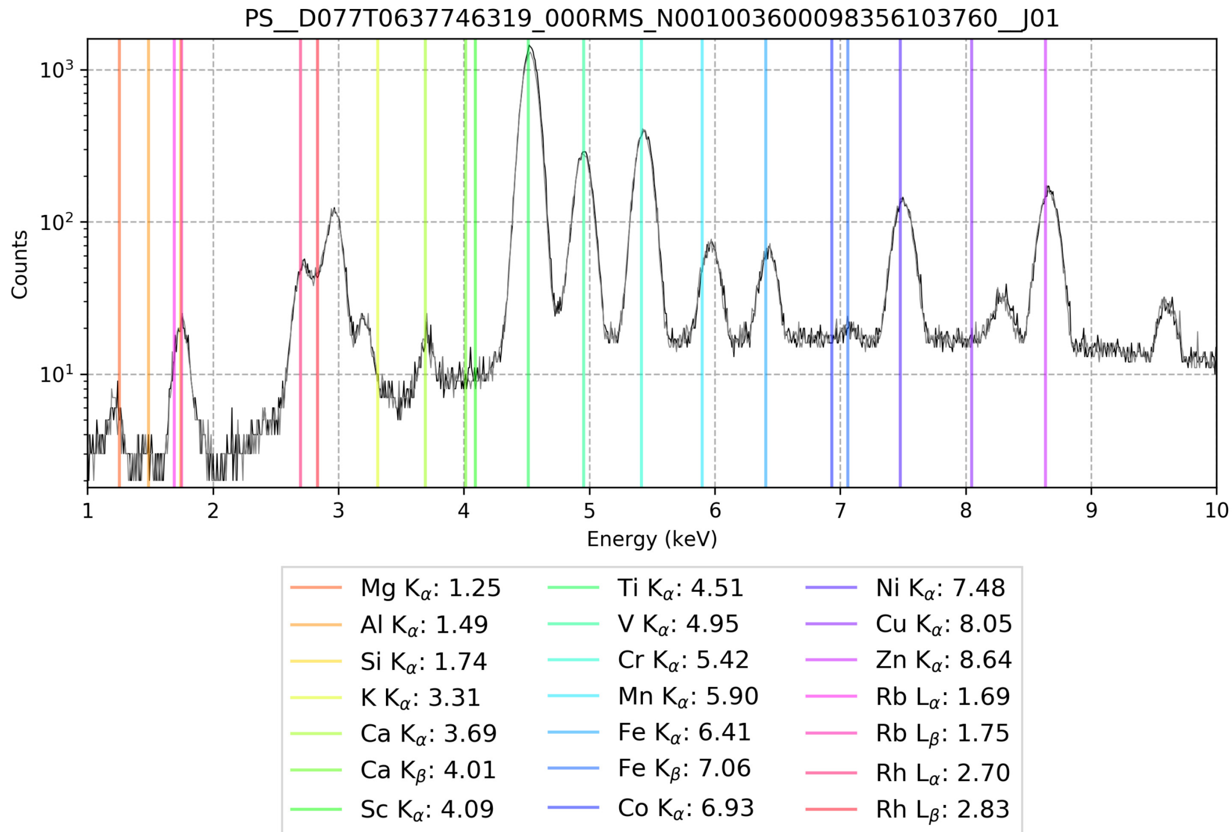


Figure 13 - A representation of the Bulk Max Value histogram with annotations indicating some common X-ray fluorescence peak locations.

5.2.3 Histogram Bulk Summed Spectrum (RBS)

An MSA file containing a header (defined by '#' character at the start of each row) and a series of rows representing the energy-calibrated bulk sum spectra (with energy calibration parameters – XPERCHAN and OFFSET in the header). The bulk sum value is the sum of all non-dwell histograms collected. Energy resolution and detector temperature are expected to be relatively constant during a map activity, and a characterization of energy resolution at each point is not necessary. Each row contains two integer values (comma-delimited), representing bulk sum intensity at each channel for each detector.

The channel number may be converted to an energy value using the XPERCHAN and OFFSET values (of type double and double, respectively) present in the header:

energy (eV) = channel_number*XPERCHAN + OFFSET

The REALTIME (double) represents the total time that the spectrometer was acquiring an X-ray signal (live time + dead time), and is typically equivalent to the commanded integration time for a histogram

The LIVETIME (double) represents the total time that the spectrometer actually collected X-rays. This time will be less than the REALTIME due to brief pauses during acquisition from data transfer/readouts, resetting the preamplifier, and pulse pile-ups (overlapping pulses).

Example Snippet:

```
#FORMAT      : EMSA/MAS spectral data file
#VERSION     : TC202v2.0 PIXL
#TITLE       : BHVO Example, sum spectrum, Detector 0
#DATE        : 31-JAN-2017     Date in the format DD-MMM-YYYY, for example 07-JUL-
2010
#TIME        : 00:00           The time of day at which the spectrum was recorded,
in 24-hour format
#OWNER       : PIXL Flight Model       (PIXL will use this to indicate which
instrument took the data.)
#NPOINTS     : 4096     Number of data points in the spectrum (This can be zero for
configuration only files)
#NCOLUMNS    : 2     Number of data columns in the spectrum (This can be zero for
configuration only files)
#XUNITS      : eV
#YUNITS      : COUNTS
#DATATYPE    : YY
#XPERCHAN    : 8, 8   eV per channel (separate by commas if more than one detector)
#OFFSET      : 0, 0         eV of first channel  (separate by commas if more than
one detector
#SIGNALTYPE  : XRF
#YP_TEMP     : 32.537
#LIVETIME    : 16691.931641, 16704.445312   seconds (separate by commas if more than
one detector)
#REALTIME    : 16810.0, 16810.0   seconds (separate by commas if more than one
detector)
#SPECTRUM    : start of spectrum data
0, 0
0, 0
0, 0
0, 0
0, 0
0, 0
```

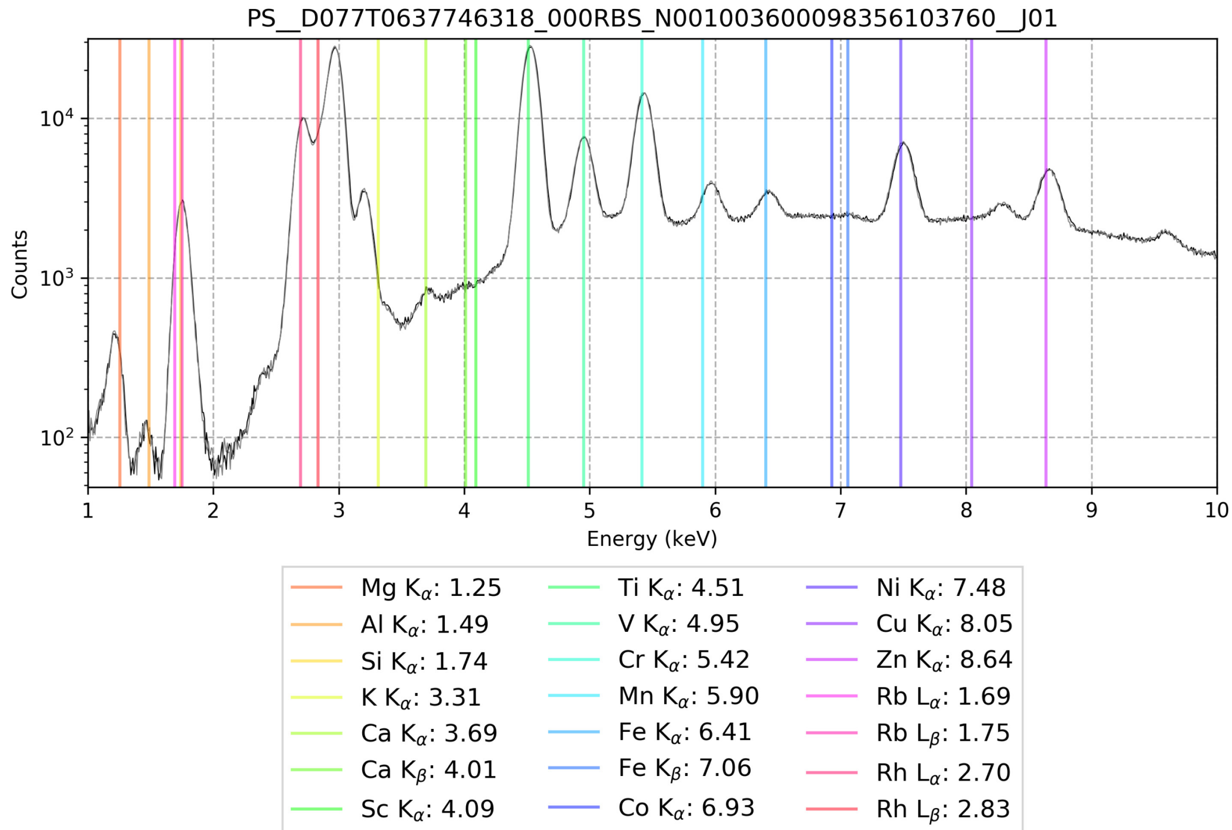


Figure 14 – A representation of the Bulk Summed Spectrum histogram with annotations indicating some common X-ray fluorescence peak locations

The bulk sum uncertainties on the bulk sum quantification are included in the RBQ product: abs_err K, abs_err L, abs_err M as described in Section 5.3.1, item 4.

5.2.4 Localized Full Spectra (RFS)

This product is represented by a single CSV file with four mandatory tables (or spreadsheets) and four optional tables providing dwell spectral data:

A Housekeeping Data table contains the following columns: SCLK_A, SCLK_B (each of type int, indicating the SCLK time associated with each point for each detector), PMC (int, the PIXL Motion Counter associated with each point), real_time_A, real_time_B (each of type double, the “real” time – measurement time - of each measurement at each point for each detector), live_time_A, live_time_B (each of type double, the “live” time – the time during which the SDD is collecting data – of each measurement at each point for each detector), yellow_piece_temp (of type double, 1K PRT, 4-wire: yellow piece temperature sensor), XPERCHAN_A, XPERCHAN_B (each of type floating-point, the energy slope needed for the energy calibration of detectors A and B, respectively), OFFSET_A, OFFSET_B (each of type int, the energy offset needed for the energy calibration of detectors A and B, respectively).

The channel number may be converted to an energy value using these values:

Energy (eV) = channel_number * XPERCHAN + OFFSET

Example Snippet, Housekeeping Data:

```
SCLK_A,SCLK_B,PMC,real_time_A,real_time_B,live_time_A,live_time_B,
yellow_piece_temp,XPERCHAN_A,XPERCHAN_B,OFFSET_A,OFFSET_B
654666097,654666097,8,10,10,9.92795,9.93502,-262.454,8,8,0,0
654666110,654666110,9,10,10,9.92772,9.93463,-262.454,8,8,0,0
654666123,654666124,10,10,10,9.92793,9.93466,19.907,8,8,0,0
```

A position data table contains the following columns: PMC (int, the PIXL Motion Counter associated with each point), x, y, z (each of type double) – referring to the X-ray beam locations in the PIXL base frame at the target surface.

Example Snippet, Position Data:

```
PMC,x,y,z
8,-0.136972,0.135652,0.248142
9,-0.136909,0.135544,0.24814299999999997
10,-0.136847,0.135436,0.248144
11,-0.136784,0.135328,0.24814499999999998
12,-0.136722,0.135219,0.248146
13,-0.136659,0.13511099999999998,0.248146
```

Histogram data from detector A and B will be saved to separate tables (spreadsheets), with 4096 columns each. The column names contain a prefix to indicate the detector used (A/B) followed by an underscore (‘_’) and an index (1-4096). All values are int.

Example Snippet, Histogram Data A and B:

```
A_1,A_2,A_3,A_4,A_5,…,A_4095,A_ 4096
0,0,0,0,0,…,0,0
0,0,0,0,0,…,0,0
0,0,0,0,0,…,0,0
0,0,0,0,0,…,0,0

B_1,B_2,B_3,B_4,B_5,…,B_4095,B_4096
0,0,0,0,0,…,0,0
0,0,0,0,0,…,0,0
0,0,0,0,0,…,0,0
0,0,0,0,0,…,0,0
```

In each case, the number of rows is equivalent to the number of points in a scan.

If dwell spectral data is present, the product file will contain four additional tables having the same headers and formats as each of those above.

5.2.5 MCC Context Image w/ Mark-up (RCM)

Annotated images showing X-ray beam locations as an overlay, with the (x, y) pixel positions of each X-ray beam location marked on the overlay. The images are stored as a multi-layer .TIF file, with the first layer containing the greyscale MCC context image and the second layer containing an image with X-ray bean locations (pixel value 255).

At the nominal 2.5 cm working distance, the pixel scale is approximately 50 μm/pixel. A more precise pixel scale for each X-ray beam location may be determined from the coordinates in the RXL product (Section 5.2.1), where the ratio of the distance between two points in the PIXL base frame and the distance between two points in the image pixel space represent the pixel scale for a particular region of the image.

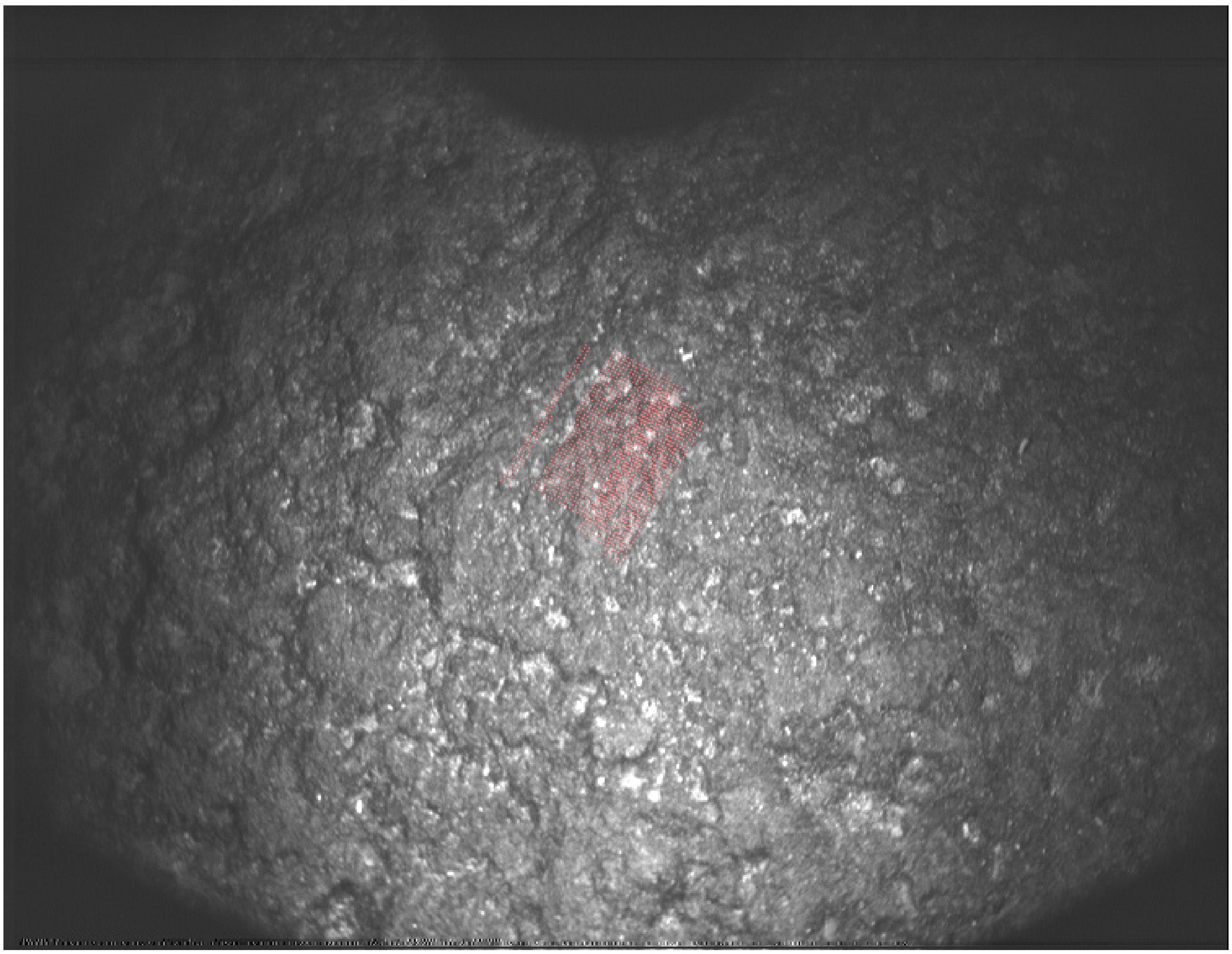


Figure 15 – MCC Context Image with Mark-up example

5.2.6 PseudoIntensity Plots/Maps (RPM)

Pseudointensity values represent a low-bandwidth summary of the elemental composition within a measurement for tactical purposes, but should be considered less robust than the quantitative results produced by PIQUANT*•, a software tool to analyze PIXL spectra and generate quantitative element compositions. The pseudointensity values are generated from on-board processing algorithms, which calculate spectral backgrounds, subtract the background, and calculate the integrated intensity for a region associated with 22 elements lines and 10 element ratios. The default pseudointensity element and element ratios and their corresponding channels and energy ranges are provided in Table 5. The pseudointensity channel ranges may be re-defined during uplink of PIXL commands, and may therefore deviate from the values presented in Table 5. The product CSV file contains two tables, a position table and a pseudointensity data table.

The position table contains the PMC and the X-ray beam location in the site frame:

- PMC (int): The PIXL Motion Counter is a counter representing a change to the PIXL Hexapod position. The counter starts at 0 when PIXL is powered on (presumably with the hexapod in the "homed" position) and increases by 1 each time the hexapod is moved.

- x, y, z (double): The position of an X-ray beam location on the target, relative to the PIXL base frame.

The pseudointensity data table contains the calculated pseudointensity value (double) for each position for each of the 32 entries. The row number in the pseudointensity table corresponds to the row number in the position table. The energy channels associated with each of the pseudointensity values are provided in **Table 5**.

Uncertainties for pseudo-intensities are not computed on-board, and therefore are not included in RPM RDR or the related EPN/EPD EDR data products.

Channel Name	Element	Channel Range	Energy (keV)
pi1	Na	122-142	1.04
pi2	Mg	148-170	1.25
pi3	Al	176-200	1.49
pi4	Si	207-233	1.74
pi5	P	241-268	2.01
pi6	S	277-306	2.31
pi7	Cl	315-346	2.62
pi8	K	400-435	3.31
pi9	Ca	446-483	3.69

*• PIQUANT is a non-JPL software suite.

pi10	Ti	547-588	4.51
pi11	Ce	588-630	4.84
pi12	Cr	658-703	5.41
pi13	Mn	718-765	5.90
pi14	Fe	780-829	6.40
pi15	Ni	913-966	7.48
pi16	Ge	1211-1271	9.89
pi17	As	1293-1355	10.54
pi18	Zn	1057-1113	8.64
pi19	Sr	1742-1814	14.17
pi20	Y	1840-1914	14.96
pi21	Zr	1938-2014	15.75
pi22	Ba	542-582	4.47
pi23	K/Ca	N/A	N/A
pi24	Si/Ti	N/A	N/A
pi25	Si/Zr	N/A	N/A
pi26	Si/Cr	N/A	N/A
pi27	Ti/Fe	N/A	N/A
pi28	Ca/Fe	N/A	N/A
pi29	Mn/Fe	N/A	N/A
pi30	Ca/Sr	N/A	N/A
pi31	Ca/Ba	N/A	N/A
pi32	Sr/Ba	N/A	N/A

Table 5 - Energy channel and pseudointensity value associations

Example Snippet, Position Table:

```
PMC,x,y,z
8,-0.136972,0.135652,0.248142
9,-0.136909,0.135544,0.24814299999999997
10,-0.136847,0.135436,0.248144
11,-0.136784,0.135328,0.24814499999999998
12,-0.136722,0.135219,0.248146
13,-0.136659,0.13511099999999998,0.248146
14,-0.136597,0.13500299999999998,0.24814699999999998
15,-0.136534,0.13489400000000001,0.248148
16,-0.136472,0.134785,0.24814899999999998
17,-0.136409,0.134677,0.24815
18,-0.136347,0.134569,0.24815
19,-0.136284,0.134459,0.248151
20,-0.136223,0.134352,0.248152
21,-0.136159,0.134244,0.248153
22,-0.136098,0.134135,0.24815399999999999
```

Example Snippet, Pseudointensity Data Table:

```
pi1,pi2,pi3,pi4,pi5,pi6,pi7,pi8,pi9,pi10,pi11,pi12,pi13,pi14,pi15,pi16,pi17,pi18,pi1
9,pi20,pi21,pi22,pi23,pi24,pi25,pi26,pi27,pi28,pi29,pi30,pi31,pi32
1e-
06,3.0,33.5449,144.873,11.5024,0.774356,6.61065,8.44088,5.51989,0.628033,0.227429,0.
15268800000000002,0.109182,3.79981,5.95684e-10,7.806879999999999e-
10,0.0297344,0.0192987,0.465467,0.278606,0.331513,0.552673,1.52917,230.677,437.005,9
48.816,0.16527999999999998,1.45268,0.0287335,11.8588,9.98763,0.84221
6.01897e-
07,0.549558,15.569,59.4034,1.85037,0.47012,5.25699,8.00886,4.43468,0.639637,0.116157
,0.0159545,0.0278427,4.14015,5.83267e-
10,0.0767018,0.0699654,0.01208,0.234296,0.311699,0.54579,0.618023,1.80596,92.8705,10
8.839,3723.31,0.154496,1.07114,0.00672504,18.9277,7.17559,0.379106
1e-
06,3.0,68.0,743.971,54.0,1.38976,5.93185,8.15435,4.645,0.662227,0.0980014,8.74416999
9999998e-10,0.094291,4.07666,6.18861e-10,0.0449089,8.134739999999999e-
10,5.996659999999999e-
10,0.477858,0.34609,0.508826,0.661209,1.75551,1123.44,1462.13,743970000.0,0.162443,1
.13941,0.0231295,9.72045,7.025,0.722704
6.77094e-
07,1.85465,19.1411,90.8103,1.99477,1.03054,5.41167,8.13203,3.70523,0.619919,0.107246
,0.0606614,0.0587521,4.25324,6.32365e-10,0.086299,0.08475210000000001,6.16161e-
10,0.259973,0.229647,0.50079,0.591408,2.1947400000000004,146.487,181.334,1497.0,0.14
5752,0.8711540000000001,0.0138135,14.2524,6.26511,0.439583
4.87079e-
07,1.33417,13.605,105.247,4.79221,1.11387,5.8132800000000002,9.60383,3.97768,0.474529
,0.0185574,0.0183451,0.016321799999999997,3.38731,6.5816e-10,7.2558e-
10,0.00959701,0.00652367,0.382455,0.318278,0.488388,0.448618,2.41443,221.792,215.498
,5737.03,0.14009000000000002,1.17429,0.00481852,10.4004,8.866530000000003,0.852518
```

Figure 16 is an example pseudointensity plot/map, showing the intensity variability for a single pseudointensity channel, and interpolating between points to generate a map. In this case, dark regions represent low intensity, bright regions represent high intensity.

Figure 16 – Pseudointensity Plot/Map Example

5.3 **Derived Data Products**

5.3.1 Histogram Bulk Quantitative Measurement (RBQ)

This product contains an XML label and a CSV file containing a list of elements and their corresponding bulk concentration in the sample (averaged over an entire map) in weight percent.

This CSV file contains the results of the quantitative analysis applied to the bulk sum spectrum – a sum of all spectrum intensity values over all points in an observation. The CSV file contains four tables:

1. SCLK and PMC:
    - SCLK (int): the spacecraft clock time – A nine-digit integer representing the start of the PIXL measurement
    - PMC (int): The PIXL Motion Counter is a counter representing a change to the PIXL Hexapod position. The counter starts at 0 when PIXL is powered on (presumably with the hexapod in the "homed" position) and increases by 1 each time the hexapod is moved.
2. Detector Characteristics:

- live_time (double): the live time
- total_counts (int): the total counts collected at all points

3. Quantitative Results Fit:

- element sum % (double): The wt% sum for all elements in the fit
- energy_correction_offset (double): The energy offset applied to the spectrum
- slope_change_% (double): The percent change to the energy slope
- reduced_chi_sq (double): The reduced chi square value of the simulated spectrum from the derived fit
- eV start (double): The energy value associated with the first channel of the histogram
- eV per channel (double): The energy slope applied to the energy calibration
- detector resolution (eV) (double): The FWHM of the energy spectrum at 5.984 keV
- fano (double): Controls the slope of the X-ray detector resolution vs. the square root of the energy

4. Quantitative Analysis Results: The first column represents the element or oxide (string), the second column represents the calculated weight % composition (double), the third column indicates the emission lines considered in the fit (K, L, M) (double), the next three columns represent the calculated intensity for the K, L, and M emission lines for each element (all of type double), the final three columns represent the absolute percent error for the corresponding weight % values for the K, L, and/or M emission lines (all of type double).

   The names in the element column are listed as oxides for some species and elements for others, according to typical XRF convention, to provide total oxide abundance in addition to elemental abundance. Elements that are included in this table have been included in the quantification calculation for the bulk sum spectrum, and may not necessarily match the element/oxide names in the example table below. The matrix element oxide row represents the total calculated oxide abundance, the Rh_coh row represents the coherent (Rayleigh) scatter line, and the Rh_inc row represents the incoherent (Compton) scatter from the corresponding emission line from the Rh anode of the X-ray tube.

Example Snippet:

```
Spacecraft Clock,PMC
654692662,1692
live time,total counts
16691.93,42194008
16585.21,41983802
Element sum %,energy correction offset eV,slope change %,reduced chi sq,eV start,eV
per channel,detector resolution (eV),fano
73.4,-17.43,0.18,933.47,-17.4,8.0143,177,0.089
element,wt%,emission line,int K,int L,int M,abs_err K, abs_err L, abs_err M
SiO2,64.72, K,1542670.6,0,0,3.3,0,0
K2O,4.79, K,11184947,0,0,0.9,0,0
CaO,1.52, K,4582012,0,0,3,0,0
Ti,0.119, K,910429.3,0,0,9.2,0,0
Cr,0, K,0,0,0,0,0,0
Mn,0.0158, K,198209.2,0,0,47.2,0,0
Fe2O3,1.21, K,11509937,0,0,1.7,0,0
SO3,0.94, K,181174.5,0,0,19,0,0
Cu,0.0071, K L,84431.4,0,0,34.6,0,0
matrix element O,36.7273, N/A,0,0,0,0,0,0
Ar,0, K,893211.1,0,0,0.16,0,0
Rh coh,0, L L,0,1003802.7,0,0,0.15,0
```

5.3.2 Rock Composition Sums (RCA, RCB, RCC)

These products contain the elemental composition for each PMC, calculated for Detector A only (RQA), Detector B only (RQB), and a combination of Detectors A and B (RQC). A PIXL Science Team member generates the quantification from each histogram using PIQUANT, which is called from the PIXLISE** visualization tool. Quantifications for each PMC within a map are represented as a row in the RQA, RQB, and RQC CSV files.

The CSV file contains a single table with the PIQUANT quantification weight % (wt%) values and absolute wt% errors for each PMC. The columns in the table are defined below:

- PMC (int): The PIXL Motion Counter is a counter representing a change to the PIXL Hexapod position. The counter starts at 0 when PIXL is powered on and increases by 1 each time the hexapod is moved.
- Element or oxide weight percent (Na2O_wt%, MgO_wt%, Al2O3_wt%, SiO2_wt%, P2O5_wt%, SO3_wt%, Cl_wt%, K2O_wt%, CaO_wt%, TiO2_wt%, Cr2O3_wt%, MnO_wt%, FeO-T_wt%, NiO_wt%, ZnO_wt%, Br_wt%): The calculated weight % composition for each element or oxide, which assumes a homogeneous specimen (double).
- Absolute uncertainty in element or oxide weight percent (Na2O_wt%_err, MgO_wt%_err, Al2O3_wt%_err, SiO2_wt%_err, P2O5_wt%_err, SO3_wt%_err, Cl_wt%_err,

** PIXLISE is a non-JPL software tool used for analysis.

K2O_wt%_err, CaO_wt%_err, TiO2_wt%_err, Cr2O3_wt%_err, MnO_wt%_err, FeO-T_wt%_err, NiO_wt%_err, ZnO_wt%_err, Br_wt%_err): The calculated absolute percent uncertainty for the corresponding element or oxide weight %, including both calibration and statistical contributions (double).

Example Snippet

```
PMC, Na2O_wt%, MgO_wt%, Al2O3_wt%, …, Br_wt%, Na2O_wt%_err, MgO_wt%_err,
Al2O3_wt%_err, …, Br_wt%_err
93, 4.7445, 8.782, 7.4014, …, 0.0029, 1.3395, 0.6185, 0.4374, …, 0.0173
94, 0.4423, 2.4276, 3.2949, …, 0.0044, 0.8542, 0.5976, 0.5701, …, 0.0151
95, 0.6044, 5.5839, 7.0146, …, 0.0013, 1.0359, 0.4385, 0.4089, …, 0.0145
96, 0, 14.4865, 8.1753, …, 0.0638, 0, 0.9065, 0.4796, …, 0.035
97, 3.6238, 10.8472, 7.1622, …, 0.0186, 1.5178, 0.7262, 0.4285, …, 0.0427
98, 0, 12.3242, 5.8883, …, 0.0221, 0, 0.8095, 0.3683, …, 0.0475
99, 3.8721, 10.203, 6.0567, …, 0.0299, 1.4798, 0.6991, 0.3741, …, 0.0478
…
216, 0.3791, 6.9369, 8.4682, …, 0.027, 1.0646, 0.5031, 0.4813, …, 0.0461
```

6. STANDARDS USED IN GENERATING PRODUCTS

6.1.1 PDS Standards

The PIXL RDR data products comply with Planetary Data System standards as specified in Applicable Documents 4, 5, 6, and 7. The PIXL Bundle SIS (Applicable Document 3) describes the organization and content of the PIXL archive in the PDS.

6.1.2 Time Standards

The following time standards and conventions are used throughout this document, as well as the M2020 project for planning activities and identification of events.

Time Format	Definition
SCET	Spacecraft event time. This is the time when an event occurred on-board the spacecraft, in UTC. It is usually derived from SCLK.

SCLK	Spacecraft Clock. This is an on-board 64-bit counter, in units of nano-seconds and increments once every 100 milliseconds. Time zero corresponds to midnight on 1-Jan-1980.
ERT	Earth Received Time. This is the time when the first bit of the packet containing the current data was received at the Deep Space (DSN) station. Recorded in UCT format.
Mean Local Solar Time	Mean Local Solar Time (MLST). This is the local solar time defined by the local solar days (sols) from the landing date using a 24 "hour" clock within the current local solar day (HR:MN:SC). Since the Mars day is 24h 37m 22s long, each unit of LST is slightly longer than the corresponding Earth unit. LST is computed using positions of the Sun and the landing site from SPICE kernels. If a landing date is unknown to the program (e.g. for calibration data acquired on Earth) then no sol number will be provided on output MLST examples: SOL 12 12:00:01 SOL 132 01:22:32.498 SOL 29
RCT	Record Creation Time. This is the time when the record or packet was created on the ground. Each ground subsystem may tag a product with its own timestamp. Recorded in UTC format.
True Local Solar Time	This is related to LST, which is also known as the mean solar time. It is the time of day based on the position of the Sun, rather than the measure of time based on midnight to midnight "day". TLST is used in all MIPL/OPGS generated products.
SOL	Solar Day Number, also known as PLANET DAY NUMBER in PDS label. This is the number of complete solar days on Mars since landing. The landing day therefore is SOL zero.

Table 6 –Time Format Definitions

6.1.3 Coordinate Frame Standards

The M2020 Frame Manager defines several dozen coordinate frames which can be used for commanding pointing among other things. Refer to the Pointing, Positioning, Phasing and Coordinate Systems (PPPCS) document [Ref X] or the Surface Attitude, Positioning and Pointing

(SAPP) Functional Design Description (FDD) [Ref X] for more details on all these coordinate frames. Only a few of them are used by the products and processes described by this SIS. This subset is described in detail in this section. The only place in this SIS where the full set of frames can appear is in the INSTRUMENT_COORD_FRAME_ID label, which is a command echo.

A subset of these frames needed for a specific image or data set are defined by the *_COORDINATE_SYSTEM groups.

Frame Name (Label Keyword Value)	Short Name (SAPP FDD)	Reference Frame (Used to Define)	Coordinate Frame	
			Origin	Orientation
ROVER_NAV_FRAME	RNAV	Enclosing SITE_FRAME	Attached to rover	Aligned with rover
ROVER_MECH_FRAME	RMECH	Enclosing SITE_FRAME	Attached to rover	Aligned with rover
LOCAL_LEVEL_FRAME	LL	Enclosing SITE_FRAME	Attached to rover (coincident with Rover Nav Frame)	North/East/Nadir
SITE_FRAME	SITE(n)	Previous SITE_FRAME	Attached to surface	North/East/Nadir
RSM_HEAD_FRAME	RSM_HEAD	ROVER_NAV_FRAME	Attached to mast head	Aligned with pointing of mast head. This corresponds to RSM_HEAD in the Frame Manager
Arm Frames: ARM_TURRET_FRAME ARM_DRILL_FRAME ARM_<BITCAR>_FRAME ARM_<SHERLOC>_FRAME ARM_<SEAL>_FRAME ARM_APXS_FRAME ARM_PORTION_FRAME ARM_SCOOP_TIP_FRAME ARM_SCOOP_TCP_FRAME	Arm Frames: TURRET DRILL BITCAR <SHERLOC> <SEAL> APXS PORTION SCOOP_TIP SCOOP_TCP	ROVER_NAV_FRAME	Attached to the tool; see PPPCS for the specific tool frame.	Aligned with tool in some way; see PPPCS [Ref X] for the specific tool Frame.
PIXL-SENSOR	PIXL sensor coordinate frame	Hexapod motion	Lower left inside corner of the sensor assembly mounting frame	Positive Z along the nominal X-ray beam axis, positive Y upwards
PIXL_BASE	PIXL base coordinate frame	PIXL sensor frame at home position	Junction of the mounting surface and two edges of the PIXL base plate	Aligned with the sensor frame

Table 7 - Coordinate Frames Used for M2020 Surface Operations

6.1.4 Rover Navigation (Rover NAV) Frame

The Rover Nav frame (RNAV) is the one used for surface navigation and mobility. By definition, the frame is attached to the rover, and moves with it when the rover moves while on the surface. Its Y origin is centered on the rover and the X origin is aligned with the middle wheels' rotation axis for the deployed rover and suspension system on a flat plane. The Z origin is defined to be at the nominal surface, which is a fixed position with respect to the rover body. The actual surface will likely not be at exactly Z=0 due to the effects of suspension sag, rover tilt, rocker bogie angles, etc. The +X axis points to the front of the rover, +Y to the right side, and +Z down (perpendicular to the chassis deck). See **Figure 17**.

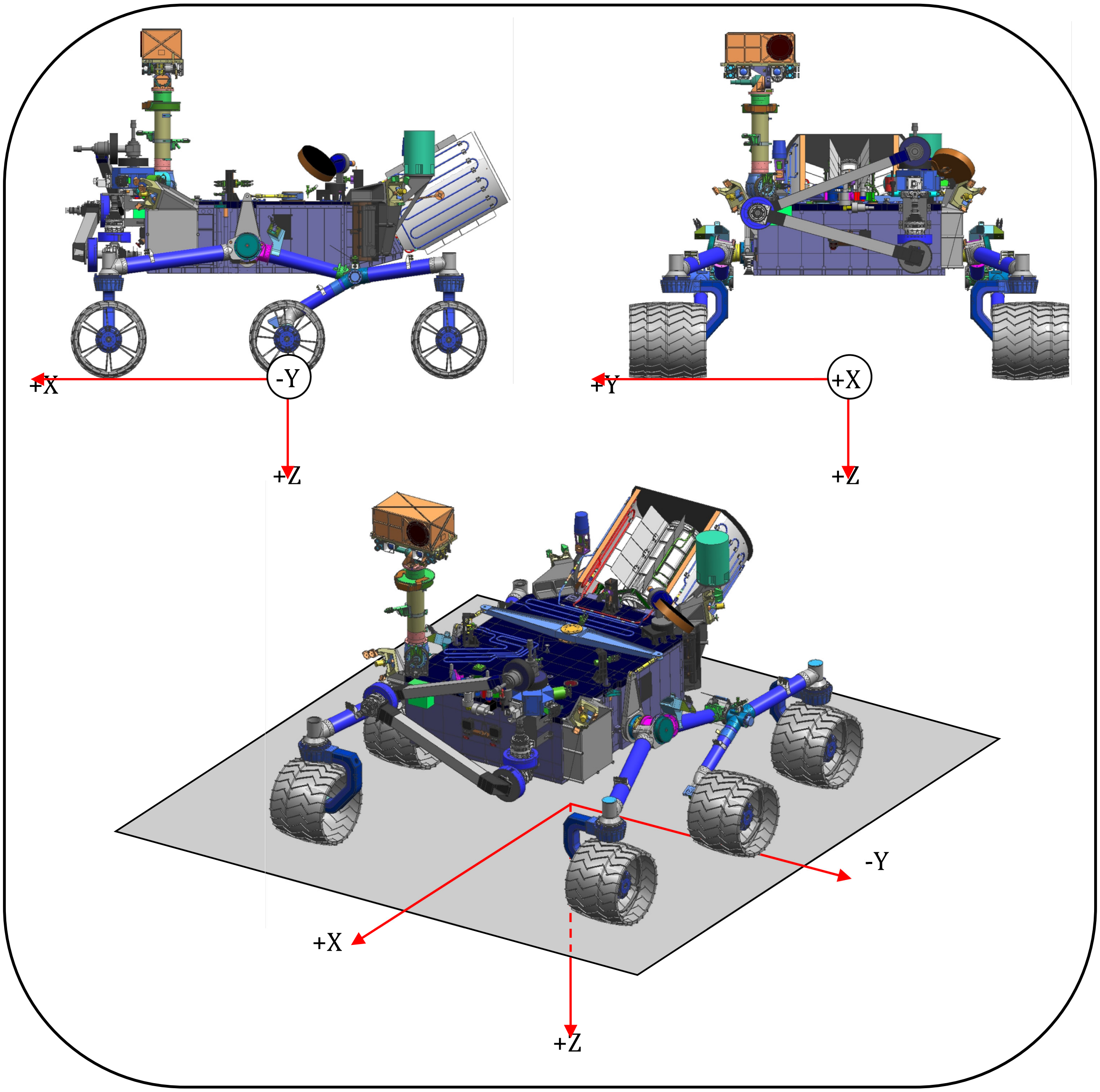


Figure 17 - Rover Navigation (RNAV) Coordinate Frame.

The Rover Nav frame is specified via an offset from the current Site frame, and a quaternion that represents the rotation between the two. A new instance of the Rover Nav frame, with a potentially unique offset/quaternion, is created every time the ROVER_MOTION_COUNTER increments.

Orientation of the rover (and thus Rover Nav) with respect to Local Level or Site is also sometimes described by Euler angles as shown in **Figure 18**, where ψ is heading, θ is attitude or pitch, and ϕ is bank or roll.

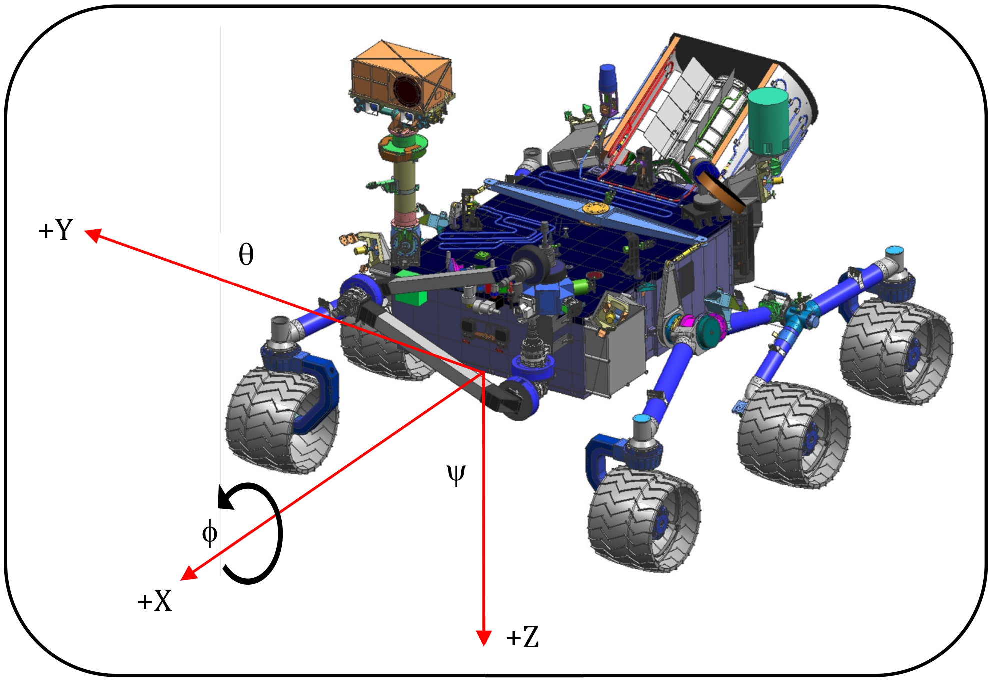


Figure 18 - Yaw, Pitch and Roll Definitions.

6.1.5 Rover Mechanical (Rover Mech) Frame

The Rover Mechanical (RMECH) frame is oriented identically to the Rover Nav frame. The origin is forward of Rover Nav by x=0.09002 meters. In other words, given a point expressed in Rover Mech, if you add (0.09002, 0.0, -1.13338) you will get the same point expressed in Rover Nav. Rover Mech is not used by any nominal products (EDR or RDR) but could appear in certain special products, generally having to do with arm kinematics.

6.1.6 Local Level Frame

The Local Level frame is coincident with the Rover Nav frame, i.e. they share the same origin at all times. The orientation is different, however. The +X axis points North, +Z points down to nadir along the local gravity vector, and +Y completes the right-handed system. Thus the orientation matches the orientation of Site frames.

Local Level frames are defined by an offset from the current Site frame, with an identity quaternion.

6.1.7 Site Frame

Site frames are used to reduce accumulation of rover localization error. They are used to provide a common reference point for all operations within a local area. Rover Nav and Local Level frames are specified using an offset from this origin. When a new Site is declared, that becomes the new reference, and the offset is zeroed. In this way, long-term localization error is relegated to the offset between Sites, becoming irrelevant to local operations, because the positions are reset with each new Site.

When a Site frame is declared, it is identical to the Local Level frame, sharing both orientation and position. However, the Site frame is fixed to the Mars surface; when the rover moves, Local Level moves with it but Site stays put. Therefore, for the Site frame, +X points North, +Z points down to nadir along the local gravity vector, and +Y completes the right-handed system.

Sites are indexed, meaning there are multiple instances. Site 1 by definition represents the landing location. New Sites are declared as needed during operations, as the rover moves away from the local area. See **Figure 19**.

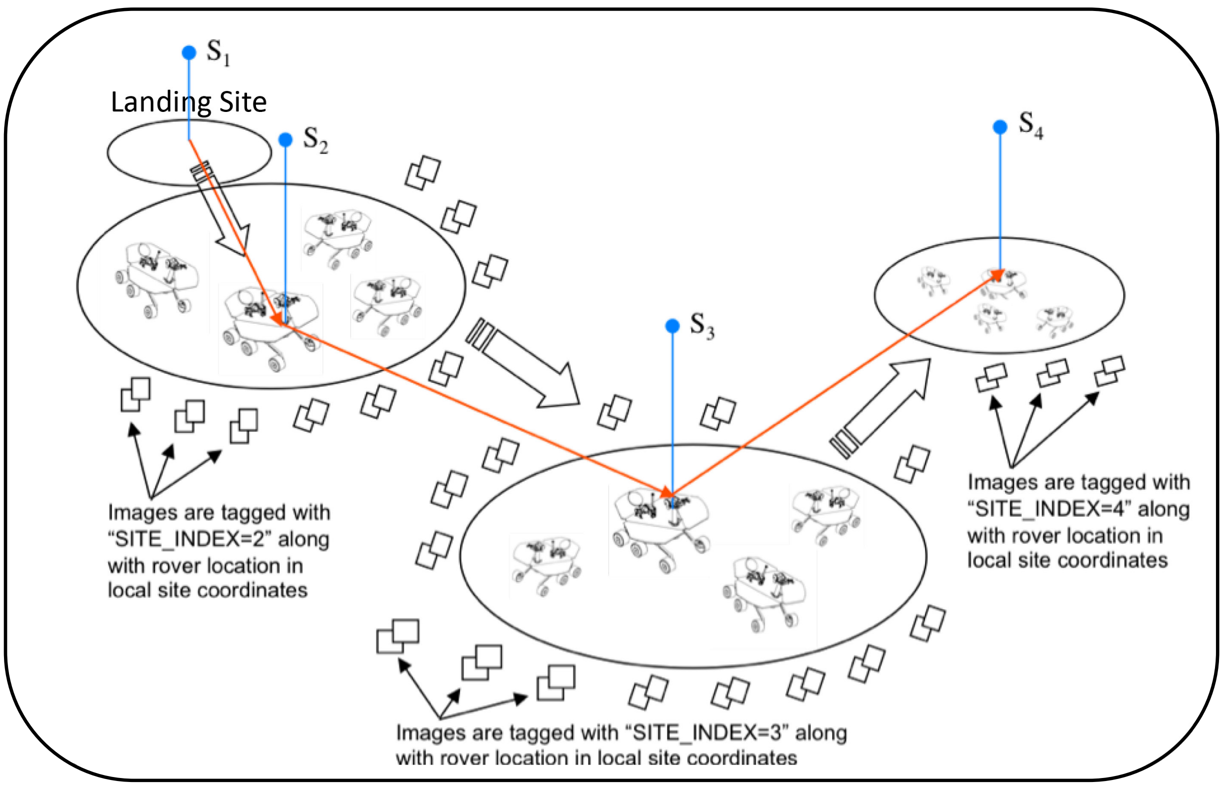


Figure 19 - Site and Rover Frames.

6.1.8 RSM Frame

The RSM frame is attached to the Remote Sensing Mast (RSM) camera head, and moves with it. See the PPPCS for specific definition. It is expressed as an offset and quaternion from the Rover Nav frame.

6.1.9 PIXL Sensor Frame

The PIXL sensor head moves to focus the X-ray beam on any given target by changing the lengths of the actuators. While the sensor head moves in the base coordinate frame, the position of all components located in the sensor head are fixed relative to one another.

6.1.10 PIXL Base Frame

The PIXL base coordinate frame is fixed relative to the M2020 Rover turret. The PIXL iFSW performs all navigation calculations in the base coordinate frame. All information passed between the PIXL Electronics, and the Rover RCE are in the PIXL base coordinate frame. All pointing information passed to the Operations Team are in the base coordinate frame (unit meters). The base coordinate frame origin is located at the junction of the mounting surface, and two edges of the base frame that is bolted to the arm turret. **Figure 20** shows an approximation of the base coordinate frame origin, with arrows showing positive X, Y, Z directions.

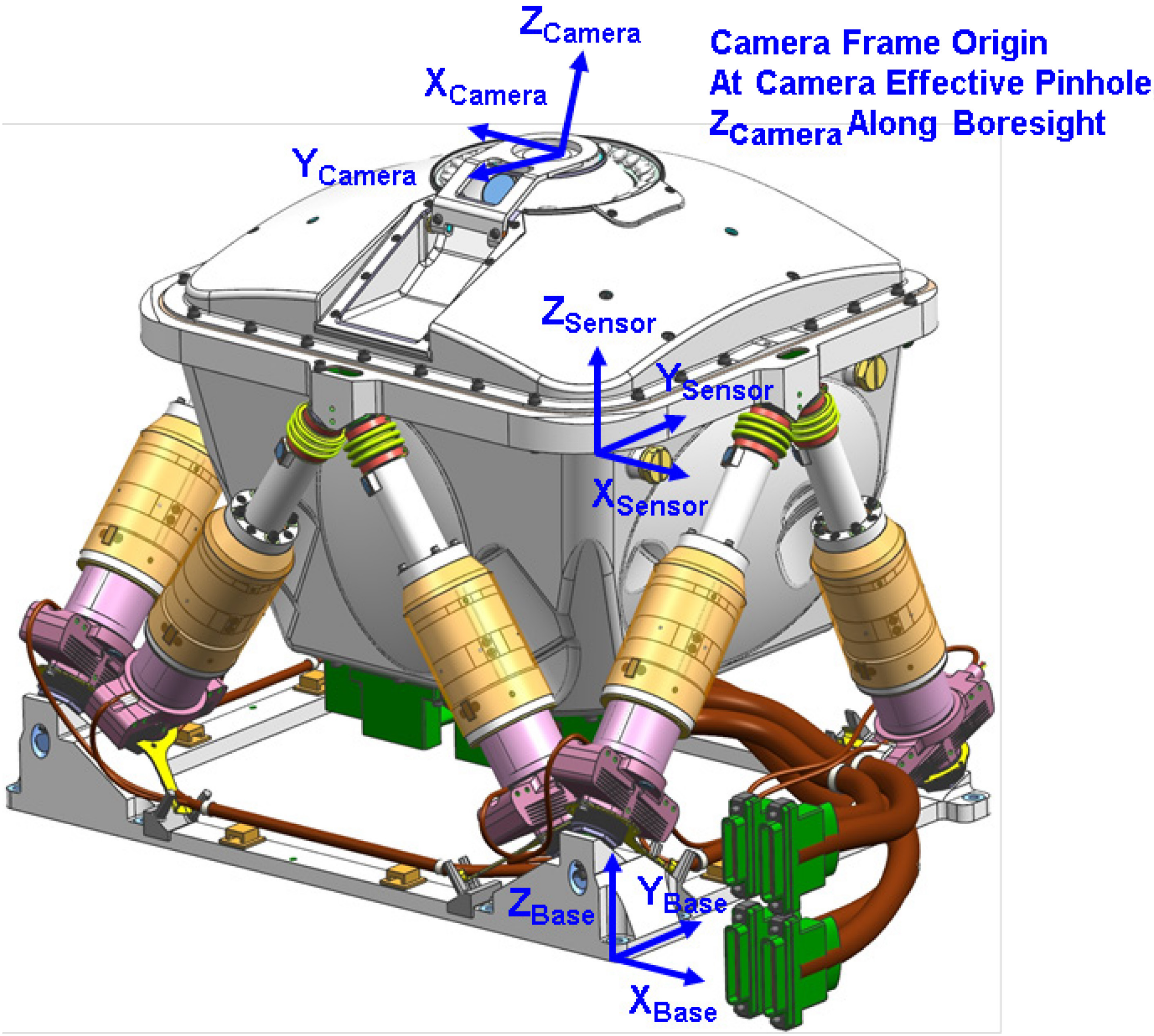


Figure 20 – Sensor Frames

The base coordinate frame, sensor coordinate frame and camera coordinate frame (not used in this document) positive axes are shown located at their approximate origin points in the PIXL Sensor Assembly. The sensor coordinate frame moves in the PIXL base coordinate frame as the hexapod is actuated to point the sensor head at successive locations. The base coordinate frame is fixed relative to the Rover Turret.

7. ACKNOWLEDGEMENTS

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