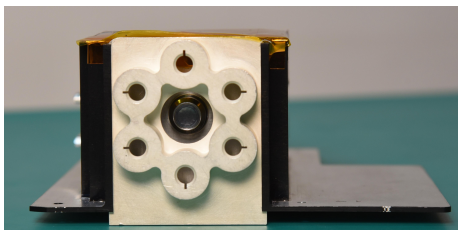
Chandrayaan-3

Alpha Particle X-ray Spectrometer (APXS)



Data Products and Archive

Software Interface Specification

Version 1.0

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Document Data Sheet

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Abstract	:	This document provides the definition of APXS data products, PDS4 archive organization. It is meant to be a reference document for users of APXS data
Keywords	:	APXS, FITS, PDS4

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Contents

1 Introduction

This Data Product and Archive Software Interface Specification for the Alpha Particle X-ray Spectrometer (APXS) instrument on-board the rover of Chandrayaan-3 mission describes the APXS data products, product file definition, generation of data products, and PDS4 archive organization. It provides the details of APXS data archived at the ISRO Science Data Archive (ISDA) at Indian Space Science Data Center (ISSDC). This document, which provides an overview of the instrument, data product definitions, etc., serves as a reference for scientists who intend to utilize the APXS data. Some acronyms used in the document and a list of reference documents are given below.

Rest of this document is organized as follows. Section 2 provides a description of the APXS instrument and details of lunar operations. The data product definition, the organization of the APXS PDS4 archive, and file nomenclature is given in section 4. Formats of the data products and sample XML label are provided in appendix.

1.1 Acronyms

APXS	Alpha Particle X-ray Spectrometer
FITS	Flexible Image Transport System
PHA	Pulse Height Analysis
APXSDAS	APXS Data Analysis Software
PDS	Planetary Data System
ISRO	Indian Space Research Organization
PRL	Physical Research Laboratory
POC	Payload Operations Centre
ISSDC	Indian Space Science Data Centre
ISDA	ISRO Science Data Archive
LID	Logical Identifier
VID	Version Identifier
UTC	Coordinated Universal Time
XML	Extensible Markup Language

1.2 Reference Documents

1. M. Shanmugam *et al.*, "Alpha Particle X-ray Spectrometer onboard Chandrayaan-3 Rover ", *Current Science*, 118(1):45 2020.
DOI:10.18520/cs/v118/i1/53-61 arXiv:1910.09232

2. N. P. S. Mithun *et al.*, "Ground calibration of Alpha Particle X-ray Spectrometer (APXS) on-board Chandrayaan-3 Pragyaan rover: An empirical approach", *Planetary and Space Science*, Volume 187, 2020.
DOI: 10.1016/j.pss.2020.104923

3. S. V. Vadawale *et al.*, "Chandrayaan-3 APXS elemental abundance measurements at lunar high latitude", *Nature*, 2024.
DOI:10.1038/s41586-024-07870-7

2 Chandrayaan-3 Alpha Particle X-ray Spectrometer (APXS)

2.1 Instrument Description

The Alpha Particle X-ray Spectrometer (APXS) on the Chandrayaan-3 rover employs the techniques of Particle Induced X-ray Emission (PIXE) and X-ray Fluorescence (XRF) to measure abundances of elements. The instrument consists of two components: radioactive source assembly and X-ray spectroscopic detector system. Alpha particles and X-rays from the radioactive sources excite the atoms of constituent elements in the target sample. The excited atoms emit fluorescence X-rays, which are recorded by the X-ray detector. APXS is configured as a single unit mounted on a motor-based mechanism at the bottom chassi of the rover. Figure 2.1 top panel shows a photograph of the flight model of the APXS instrument, and the bottom panel shows APXS on the rover model in stowed and deployed conditions. A summary of the technical specifications of APXS is given in table 2.1. A detailed description of the instrument is given in Shanmugam et al (2020).

APXS employs Cm-244 radioactive sources to provide the excitation radiation. Six Cm-244 encapsulated sources of five mCi activity are assembled circularly onto a source holder, which is a separate part from the spectrometer. The sources also have a multi-layer metallic shielding around them, except the front side, to prevent direct radiation reaching the detector of the instrument.

In order to detect the fluorescence X-rays produced by PIXE and XRF processes, APXS employs a state-of-the-art Silicon Drift Detector (SDD). SDD procured from Ketek GmbH is in the form of an encapsulated package, including the detector chip of 450 μm thickness and thermoelectric cooler. The detector module includes an 8 μm Beryllium entrance window. The specific electrode structure of SDD provides superior spectral performance in comparison to other silicon-based detectors. X-ray photon that interacts with the SDD deposits a charge

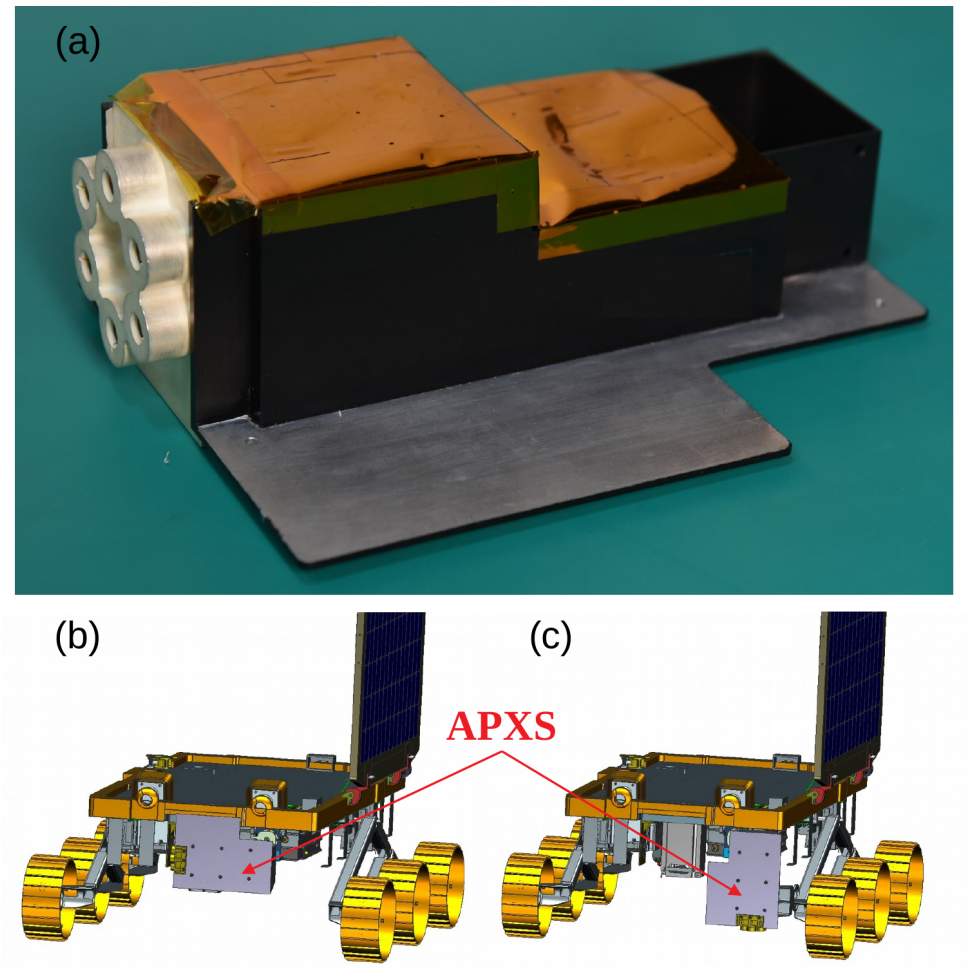

Figure 2.1: APXS instrument (a) and the 3-D model of Pragyaan rover showing the APXS in stowed (b) and deployed (c) positions.

Parameter	Specification
Energy Range	0.8 – 25 keV
Energy Resolution	~135 eV @ 5.89 keV
Number of Channels in the spectrum	4096
Detector	Silicon Drift Detector (SDD)
Detector area	30 mm^2
Radioactive source	^{244}Cm
Total source activity	30 mCi
Calibration targets	Al, Ti, SS, and Cu
Operating temperature range	-20°C – 30°C

Table 2.1: Specifications of APXS

proportional to its energy. The readout electronics converts this charge into a voltage signal, amplifies and digitizes it with an Analog to Digital Converter (ADC). The data handling system of the rover receives the ADC channel value corresponding to each detected X-ray photon from the APXS instrument. This raw data of X-ray events are stored in the solid-state recorder on the rover, which is then downloaded to the ground through the Vikram lander.

The front-end electronics of APXS is optimized to provide a resolution of better than 140 eV (typically ∼135 eV) at 5.89 keV with an energy range of 0.8 – 25 keV covering K-α lines of all major rock-forming elements from Sodium onwards along with some trace elements. The high spectral resolution of the instrument allows clear separation of fluorescence lines of different elements. As the performance of the detector is dependent on the detector temperature, it is maintained around -35 deg C with closed-loop control of thermo-electric cooler internal to SDD module and proper thermal management to radiate the heat.

The fluorescence signal depends strongly on the distance of the target from the instrument. So, it is essential to bring the instrument closer to the target surface during observations. A motor based mechanism on which APXS is mounted performs this task. In the stowed condition of the mechanism, APXS is sufficiently high from the surface, providing ample ground clearance for rover movement. For observations, the motor rotates by 90 degrees deploying APXS such that the front side of the instrument with the source assembly and the detector is brought closer to the surface. In the deployed condition, the nominal distance of the APXS detector from the surface is 55 mm. In stowed condition, APXS faces a calibration plate having multiple metallic sheets, mounted on the bottom chassis of the rover. The calibration plate acts as a protection for the sources and the detector from dust contamination. It also serves the purpose of in-flight calibration. It is fixed with targets made of aluminium, titanium, stainless steel, and copper. Observation of the calibration plate with APXS would yield a spectrum with fluorescence lines from all these targets. This spectrum can be used for energy calibration as well as to track any variations in the detector or source characteristics. The calibration plate is also coated with silver and gold. This coating acts as a protection against radiation during assembly and testing on the ground.

2.2 Summary of Lunar Operations and Observations

APXS carried out observations on the Moon during the nominal operation phase of the rover after the landing. Table 2.2 summarizes the list of APXS operations on the Moon. Total 30 operations were carried out, among which 23 were scientific observations, five were meant for engineering verifications with only calibration spectra, and data were not obtained in two observations. Data from the 23 scientific observations and five calibration observations are included in the data archive.

Obs ID	Mob ID	Start Time (UTC)	End Time (UTC)	Exposure (min)	Remarks
00*	02	25-08-2023 10:46:23	25-08-2023 10:51:29	-	Only calibration data
01	02	25-08-2023 13:24:06	25-08-2023 14:21:20	44	-
02	03	26-08-2023 14:34:41	26-08-2023 15:40:07	52	-
03	04	26-08-2023 19:16:24	26-08-2023 20:03:52	34	-
04	07	27-08-2023 18:16:24	27-08-2023 19:33:53	64	-
05	08	27-08-2023 22:16:25	27-08-2023 23:33:52	64	-
06	09	28-08-2023 14:16:23	28-08-2023 15:33:52	64	-
07*	09	28-08-2023 14:16:23	28-08-2023 15:33:52	-	Only calibration data
08*	12	28-08-2023 18:04:40	28-08-2023 18:23:33	-	Only calibration data
09*	13	28-08-2023 20:40:28	28-08-2023 20:54:54	-	Only calibration data
10*	13	29-08-2023 01:11:14	29-08-2023 01:26:38	-	Only calibration data
11	19	29-08-2023 17:20:07	29-08-2023 18:05:29	32	-
12	20	29-08-2023 19:31:02	29-08-2023 21:04:12	80	-
13	22	29-08-2023 23:51:04	30-08-2023 01:27:05	83	-
14#	22	29-08-2023 23:51:04	30-08-2023 01:27:05	-	Data not available
15	26	30-08-2023 05:47:25	30-08-2023 08:18:10	136	-
16	28	30-08-2023 12:04:18	30-08-2023 13:06:08	52	-
17	30	30-08-2023 15:07:33	30-08-2023 17:06:47	105	-
18	32	30-08-2023 19:47:36	30-08-2023 22:56:48	175	-
19	33	31-08-2023 01:16:44	31-08-2023 04:11:50	161	-
20	34	31-08-2023 05:26:59	31-08-2023 08:04:45	144	-
21	36	31-08-2023 13:17:31	31-08-2023 14:30:26	60	-
22	38	31-08-2023 22:08:53	01-09-2023 00:56:36	153	-
23	39	01-09-2023 04:32:05	01-09-2023 05:31:27	46	-
24	40	01-09-2023 06:39:17	01-09-2023 07:12:25	20	-
25	41	01-09-2023 14:30:11	01-09-2023 15:32:41	49	-
26	42	01-09-2023 18:58:57	01-09-2023 20:21:20	69	-
27#	43	01-09-2023 22:48:00	01-09-2023 23:30:00	-	Data not available
28	44	02-09-2023 02:26:41	02-09-2023 05:17:42	158	-
29	45	02-09-2023 06:29:39	02-09-2023 07:24:18	41	-

Table 2.2: Summary of APXS operations on the Moon where each operation is denoted by an observation ID from 00 to 29. Mobility ID defines the sequence of stops of the Chandrayaan-3 rover. In observations marked with #, data was not obtained and those marked with * were calibration observations for engineering verification.

3 APXS Data Products

3.1 Data Processing Level Definition

APXS data is organised into two levels, raw data (level-1) and calibrated data (level-2). Contents of raw and calibrated data is given in the table below.

The raw data collection includes the payload binary data organized into FITS format files.

PDS4 level	APXS level	Description
Raw	1	Raw payload data organized into FITS files and HK parameters in csv format
Calibrated	2	Calibrated spectrum and instrument response

Table 3.1: APXS data processing level definitions

Separate files for lunar observation, pre-calibration, and post-calibration are included. Additionally, a csv file with house keeping parameters is also included under raw directory. The calibrated data includes calibrated spectrum files in standard FITS format and the instrument response file.

3.2 Data Product files

3.2.1 Raw Data

(i) Science data file (*.fits): It tabulates the raw APXS data frames and the respective UTC, BDH packet number, BDH clock time in a FITS binary table file. The file structure is given in Appendix B.1.

(ii) HK parameter file (*.hk): Various housekeeping parameters and instrument settings along with relavant parameters of the rover are provided as a function of time in csv format. File structure (names of the columns) is given in Appendix B.2.

3.2.2 Calibrated Data

(i) Spectrum file (*.pha): APXS spectrum in gain corrected pulse invariant channels are given for calibration plate observations as well as for lunar observation. These are in standard FITS format compatible with X-ray spectral fitting packages such as XSPEC. The file structure is given in Appendix C.1.

(ii) Response file (*rsp): APXS detector response matrix in standard FITS format, for use in spectral fitting. The file structure is given in Appendix C.2.

4 APXS PDS4 Data Archive Organization

4.1 Mission Level Archive Organization

Figure 4.1 shows the mission level archive organization. Under isda archive, mission (ch3), and instrument host rover (chr) (along with those for lander and propulsion module) directories are included. Under the rover directory, context products and applicable xml schema files are stored. The instrument bundles are organized under the respective mission operation phase, primarily the normal operation phase (nop). Like apx, directories of other instruments on the rover with the respective bundle are placed under nop directory.

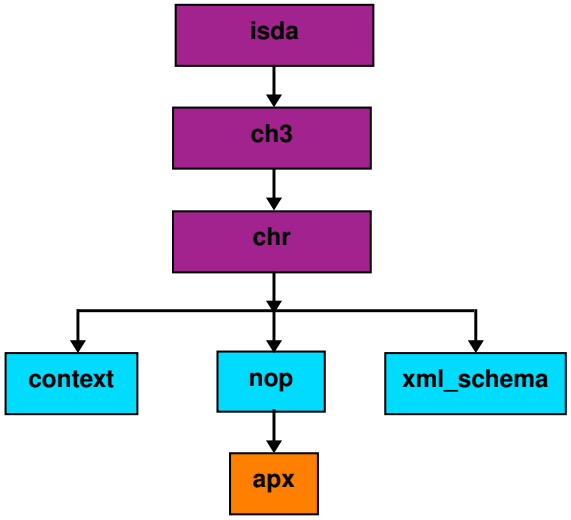

Figure 4.1: Mission level archive organization

The context directory includes the context products as defined in the PDS4 data provider's manual. Context products for the mission, instrument host or the orbiter, and all instruments are included. Each of them is an XML file with a unique LID which includes description of the respective component like mission or instrument. Data and other products in the archive are referenced to these context products by referring to their LIDs in the product labels. LIDs for the context products of Chandrayaan-3 mission, Chandrayaan-3 rover, and APXS instrument are listed below:

- `urn:isro:isda:context:investigation:mission.chandrayaan3`
- `urn:isro:isda:context:instrument_host:spacecraft.ch3rover`
- `urn:isro:isda:context:instrument:apx.ch3rover`

The XML schema directory includes the applicable XML schemas for the PDS4 labels in the archive.

4.2 APXS Instrument Bundle

All data products and other products such as documents related to APXS are included in an instrument bundle. The APXS instrument bundle then includes multiple collections for each type of products like data, document, calibration, and miscellaneous. Figure 4.2 shows the organization of individual collections under the apx instrument bundle.

The data collection includes day-wise raw and calibrated data products and labels of APXS. Documents related to APXS data are included as document collection and calibration collection has the required calibration information. The APXSDAS is included under the miscellaneous collection. The instrument level bundle and association to collections are defined in the bundle_apx.xml file under the main instrument directory. For easy reference, a readme file with the

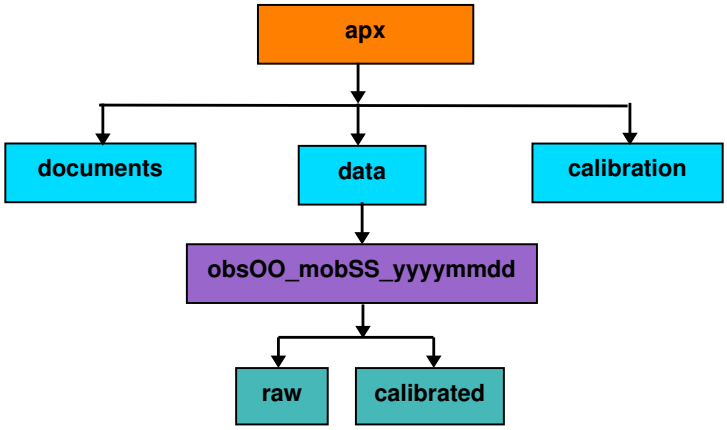

Figure 4.2: APXS instrument bundle organization

bundle organization is also included there. Details of the contents under each collection is given in the next section.

4.2.1 LID Definition

Every product in a PDS archive is assigned with a unique logical identifier (LID). The products also have a version identifier (VID) so that multiple versions of the same product can be uniquely identified. LIDs are defined following the standards defined in the PDS4 data provider's handbook and the Chandrayaan-3 archive conventions.

In the case of APXS, the LIDs for the instrument bundle, collections, and basic products are defined as per the below convention:

- **Bundle LID:** The bundle LID for APXS is defined as
  `urn:isro:isda:ch3_chr.apx`
  where `ch3_chr.apx` is the unique bundle id.

- **Collection LID:** These are formed by appending the collection id to the bundle LID defined above. Each collection under the APXS bundle has a unique id and is defined in table 4.1.

- **Product LID:** LIDs for basic products are formed by appending the unique product id to the collection's LID as:
  `urn:isro:isda:ch3_chr.apx:<collection_id>:<product_id>`
  The `<product_id>` for each type of products in the collections are defined in the next section.

Collection	LID	Contents
data	`urn:isro:isda:ch3_chr.apx:data`	Raw and calibrated data products
document	`urn:isro:isda:ch3_chr.apx:document`	Documents associated with APXS data products
calibration	`urn:isro:isda:ch3_chr.apx:calibration`	Calibration data for APXS to get abundances

Table 4.1: LID definition for APXS bundle collections

4.3 APXS Bundle Collections

This section provides the details of contents in each of the collections in the APXS bundle. Apart from the products and labels, each collection directory also include one inventory csv file with the LIDs of all products present in the collection and an XML file that defines the collection. These files are named as `collection_<collection_id>_inventory.csv` and `collection_<collection_id>_inventory.xml`, respectively.

4.3.1 Data collection

Figure 4.3 shows the product files which are included in the data collection. Apart from the FITS product files (formats in appendix), each of them will have an associated PDS4 label file and each product is assigned with a unique product ID. Nomenclature of these files, label files, and product ID definition is given below.

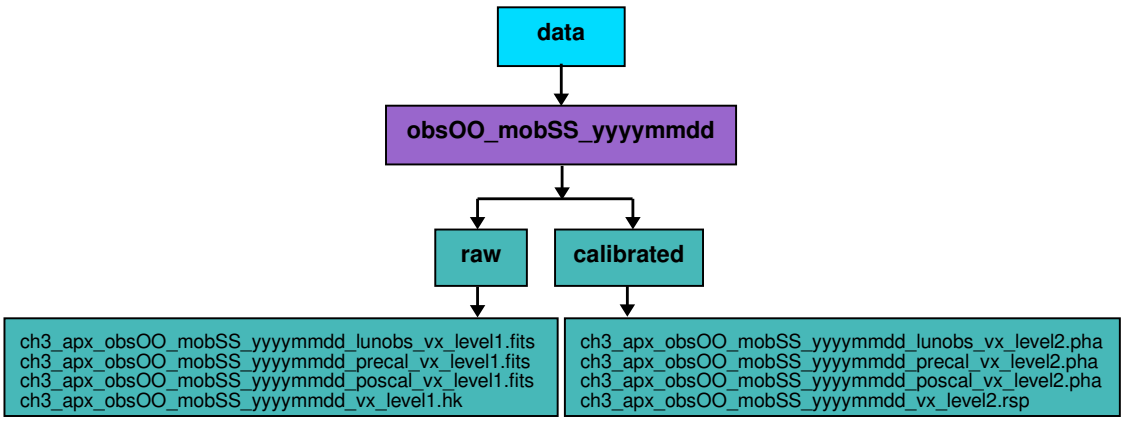

Figure 4.3: APXS data collection contents

Nomenclature of product files and labels and product ID

APXS raw (level-1) and calibrated (level-2) products have the following scheme of nomenclature:

Field	Description
ch3	Acronym for mission name Chandrayaan-3
apx	Acronym for instrument name APXS
OO	APXS Observation sequence ID (00-29)
SS	Rover mobility ID
YYYYMMDD	Start date of observation
OBSTYP	Type of observation: precal/poscal/lunobs (not applicable for rsp file)
X	Version number of the file starting from 1. It will increment on successive reprocessing (if required)
N	Denotes level of data product - either 1 or 2
extn	Extension denoting the type of product as defined in table 4.3

Table 4.2: Definition of fields in APXS file nomenclature

Extension (extn)	Product file
fits	Science data file
hk	Housekeeping data file
pha	Spectrum file
rsp	Response file

Table 4.3: Definition of extensions for each product file types.

ch3_apx_obsOO_mobSS_YYYYMMDD_OBSTYP_vX_levelN.extn

with the fields defined in Table 4.2 and extensions for each file type is given in Table 4.3.

As the archive follows PDS4 standard, each data product file mentioned above require an associated PDS4 XML label which provides information of the data product including the organization of data in the file. Names of these XML files follows below scheme for respective prodcut file:

Label file name: ch3_apx_obsOO_mobSS_YYYYMMDD_OBSTYP_vX_levelN_extn.xml
Product file name: ch3_apx_obsOO_mobSS_YYYYMMDD_OBSTYP_vX_levelN.extn

Each product also has a unique product ID which is used in the generation of LID for the product as defined in previous section. These product ID definitions are given in Table 4.4.

File type	Data level	<product_id>
Science data file	raw	obsOO_mobSS_YYYYMMDD_OBSTYP_fits
Housekeeping data file	raw	obsOO_mobSS_YYYYMMDD_hk
Spectrum file	calibrated	obsOO_mobSS_YYYYMMDD_OBSTYP_pha
Response file	calibrated	obsOO_mobSS_YYYYMMDD_rsp

Table 4.4: Definition of extensions and product id for each product file types defined in previous section.

4.3.2 Document Collection

The document collection includes relevant documents related to the APXS data products and analysis. This directory contains two documents: (i) APXS data products and archive software interface specifications (this document) and (ii) APXS Data User Guide. Both the documents are in PDF format and have an associated XML label file with the same base name. The product IDs are same as the base name of the document files.

4.3.3 Calibration Collection

Calibration collection includes the APXS measured matrix corrected line fluxes for the suite of geochemical reference materials obtained on the ground. These line fluxes are used for obtaining elemental abundances from the calibrated APXS spectrum files included in the archive. Line fluxes for ten samples as discussed in Mithun et al (2020, PSS) are given as text files. For each sample, line fluxes of K-α lines of all relavant detected elements are given for four observing distances. Errors associated with the fluxes are also given. These calibration data sets are used to derive the calibration curves and then to obtain abundances as discussed in Mithun et al (2020, PSS). A brief summary of the process is available in the data analysis guide.

4.4 Data Dissemination and Utilization

APXS data is archived at ISSDC along with data of other instruments of the Chandrayaan-3 mission. APXS data will be disseminated using a web interface named PRADAN at the following link:

```
https://pradan.issdc.gov.in/ch3/
```

Users will have to create account in this web portal to view and download the publicly available data sets. The entire apxs instrument bundle is provided as a single zip file which users can download. On extracting the compressed file, the following directory structure can be seen

```
apx/
   data/
      obsOO_mobSS_YYYYMMDD/
            raw/
                 Level-1 products and labels
            calibrated/
                 Level-2 products and labels
   documents/
      APXS user guide, DP SIS and associated labels
```

All the APXS data files can be read by using the FITS libraries available with most of the programming languages like IDL and Python for visualization or to carry out further analysis. Spectrum and response files of APXS are compatible with the X-ray astronomy spectral fitting

software tools XSPEC[1] and ISIS[2]. The spectra can be directly loaded into them following the standard procedures to carry out spectral fitting to obtain line fluxes corresponding to different elements.

For the procedures to obtain elemental abundances from the measured line fluxes, refer to the APXS Data Analysis Guide and the references therein.

[1] `https://heasarc.gsfc.nasa.gov/xanadu/xspec/`
[2] `https://space.mit.edu/cxc/isis/`

Appendix

A Contact Information

For any queries related to APXS data products please contact APXS Payload Operations Center (POC) at `apxspoc@prl.res.in`.

Name	Address	Email
Prof. Santosh Vadawale	Principal Investigator APXS, PRL Ahmedabad	`santoshv@prl.res.in`
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Mr. Mithun N. P. S.	APXS Payload Operations Center, PRL Ahmedabad	`mithun@prl.res.in`

For queries related to download of APXS data, please contact ISSDC team at `issdc@istrac.gov.in`.

B Raw Data File Format

As mentioned earlier all raw data products of APXS are in FITS file format, and are binary tables. The format of the raw science data file is provided here. For each observation, two calibration data files and one lunar observation file will be present. Note that, in archive each of the product file will be accompanied by a PDS4 XML label file.

B.1 Science file

Name

ch3_apx_obsOO_mobSS_YYYYMMDD_OBSTYP_vX_level1.fits

File format

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                   16 / number of bits per data pixel
NAXIS   =                    0 / number of data axes
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
MISSION = 'CHANDRAYAAN-3'      / Name of mission/satellite
TELESCOP= 'CH-3_ROVER'         / Name of mission/satellite
INSTRUME= 'APXS    '           / Name of Instrument/detector
```

```
ORIGIN  = 'PRLPOC  '           / Source of FITS file
CREATOR = 'apxsl1gen '         / Creator of file
FILENAME= 'APX01D32C3R00180000801232371502180004_00_level1.fits' / Name of file
CONTENT = 'L1 Science file'    / File content
DATE    = '2023-09-06T13:59:46' / Creation Date
END

XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                 1168 / width of table in bytes
NAXIS2  =                  528 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                   10 / number of fields in each row
TTYPE1  = 'Time    '           / MET Since 2017-01-01 00:00:00 UTC
TFORM1  = 'D       '           / data format of field: 8-byte DOUBLE
TTYPE2  = 'UTCString'          / UTC String
TFORM2  = '30A       '         / data format of field: String
TTYPE3  = 'FrameNumber'        / label for field
TFORM3  = 'I       '           / data format of field: 2-byte INTEGER
TTYPE4  = 'BDHTime '           / label for field
TFORM4  = 'D       '           / data format of field: Double
TTYPE5  = 'PacketLength'       / label for field
TFORM5  = 'I       '           / data format of field: 2-byte INTEGER
TTYPE6  = 'EventCounter'       / label for field
TFORM6  = 'I       '           / data format of field: 2-byte INTEGER
TTYPE7  = 'LLD     '           / label for field
TFORM7  = 'I       '           / data format of field: 2-byte INTEGER
TTYPE8  = 'GlitchCounter'      / label for field
TFORM8  = 'I       '           / data format of field: 2-byte INTEGER
TTYPE9  = 'DataArray'          / label for field (BDH frame alone, stripped L0 h
TFORM9  = '1110B       '       / data format of field: BYTE ARRAY
TTYPE10 = 'DecodingStatusFlag' / label for field
TFORM10 = 'I       '           / data format of field: 2-byte INTEGER
TUNIT1  = 's       '           / physical unit of field 1
EXTNAME = 'DATA    '           / name of this binary table extension
DATE-OBS= '2023-08-25 13:24:06.587' / Date observation start
DATE-END= '2023-08-25 13:29:12.675' / Date observation end
TSTART  =         20438646.587 / Obs Start Time; MET since MJDREF
TSTOP   =         20438952.675 / Obs Stop Time; MET since MJDREF
TIMESYS = 'UTC     '           / Time system
MJDREF  =               57754. / MJD reference
```

```
MISSION = 'CHANDRAYAAN-3'      / Name of mission/satellite
TELESCOP= 'CH-3_ROVER'         / Name of mission/satellite
INSTRUME= 'APXS    '           / Name of Instrument/detector
ORIGIN  = 'PRLPOC  '           / Source of FITS file
CREATOR = 'apxsl1gen '         / Creator of file
EXTVER  =                    1 / auto assigned by template parser
TELAPSE =     306.087999999523
HISTORY ************** APXSL1GEN **************
HISTORY l0file = APX01D32C3R00180000801232371502180004_00.pld
HISTORY l1file = APX01D32C3R00180000801232371502180004_00_level1.fits
HISTORY gcudata = no
HISTORY clobber = yes
HISTORY ************************************
END
```

B.2 Housekeeping parameter file

Name

ch3_apx_obsOO_mobSS_YYYYMMDD_vX_level1.hk

File format

This is a ASCII text file with comma separated fields. The columns of the HK files are listed below.

1. Time in UTC
2. Base Temperature
3. HV Monitor
4. Detector Temperature
5. TEC Current
6. APXS Counter
7. Inclinometer-X
8. Inclinometer-Y
9. Rover Roll Angle
10. Rover Pitch Angle
11. BDH Acquistion Status
12. APXS Heater Status

13. BDH Operation Status
14. APXS Power ON Status
15. Motor Heater Status
16. Mechanism Stowed Status
17. Mechanism Deployed Status

C Calibrated Data File Format

Similar to raw files, calibrated products are also FITS binary tables. The format of each of the calibrated data spectrum file and response file are given here. For each observation, two calibration data files and one lunar observation file will be present. Note that, in archive each of the product file will be accompanied by a PDS4 XML label file.

C.1 Spectrum file

Name

ch3_apx_obsOO_mobSS_YYYYMMDD_OBSTYP_vX_level2.pha

File format

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                   16 / number of bits per data pixel
NAXIS   =                    0 / number of data axes
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
MISSION = 'CHANDRAYAAN-3'      / Name of mission/satellite
TELESCOP= 'CH-3_ROVER'         / Name of mission/satellite
INSTRUME= 'APXS    '           / Name of Instrument/detector
ORIGIN  = 'PRL     '           / Source of FITS file
CREATOR = 'apxsgenspec '       / Creator of file
FILENAME= 'APX01D32C3R00180000801232371502180004_00_level2.pi' / Name of file
CONTENT = 'Type-I PHA file'    / File content
DATE    = '2023-09-06T13:59:46' / Creation Date
END

XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   12 / width of table in bytes
```

```
NAXIS2  =                 4096 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    3 / number of fields in each row
TTYPE1  = 'CHANNEL '           / PI Channel
TFORM1  = '1J      '           / data format of field: 1-short int
TTYPE2  = 'COUNTS  '           / Count
TFORM2  = '1E      '           / data format of field: 2-float
TTYPE3  = 'STAT_ERR'           / Error
TFORM3  = '1E      '           / data format of field: 1-float
EXTNAME = 'SPECTRUM'           / name of this binary table extension
DATE-OBS= '2023-08-25 13:24:06.587' / Date observation start
DATE-END= '2023-08-25 13:29:12.675' / Date observation end
TSTART  =         20438646.587 / Obs Start Time; MET since MJDREF
TSTOP   =         20438953.675 / Obs Stop Time; MET since MJDREF
TIMESYS = 'UTC     '           / Time system
MJDREF  =               57754. / MJD reference
MISSION = 'CHANDRAYAAN-3'      / Name of mission/satellite
TELESCOP= 'CH-3_ROVER'         / Name of mission/satellite
INSTRUME= 'APXS    '           / Name of Instrument/detector
ORIGIN  = 'PRL     '           / Source of FITS file
CREATOR = 'apxsgenspec '       / Creator of file
FILENAME=                      / Name of file
CONTENT = 'SPECTRUM'           / File content
DATE    =                      / file creation date
HDUCLASS= 'OGIP    '           / OGIP Standard
LONGSTRN= 'OGIP 1.0'           / The OGIP Longstring convention may be used
HDUCLAS1= 'SPECTRUM'
HDUVERS1= '1.2.0   '
HDUVERS = '1.2.0   '
HDUCLAS2= 'TOTAL   '           / total spec
HDUCLAS3= 'COUNT   '           / units is count NOT count/s
TLMIN1  =                    0
TLMAX1  =                 4095
DETCHANS=                 4096
AREASCAL=                   1.
BACKSCAL=                   1.
CORRSCAL=                   1.
BACKFILE= 'none    '           / Background file
EXPOSURE=      289.83377304064 / Exposure time
RESPFILE= 'ch3_apx_obs01_mob02_20230825_v1_level2.rsp'
ANCRFILE= '        '           / Ancillary response file
CHANTYPE= 'PI      '           / PHA or PI(Pulse Invariant)
```

```
POISSERR=                    F / Error in stat_err column
EXTVER  =                    1 / auto assigned by template parser
TELAPSE =     307.087999999523
HISTORY ************ APXSGENSPEC ************
HISTORY l1file = APX01D32C3R0018000080123237150218004_00_level1.fits
HISTORY specfile = APX01D32C3R0018000080123237150218004_00_level2.pi
HISTORY spectype = time-integrated
HISTORY chantype = PI
HISTORY gainfile = /data/apxsflight/apxs/01_APXXXD32C3R0018000NNNN23237150218004
HISTORY _V5_1/level2/APX01D32C3R0018000080123237150218004_00_level2.gain
HISTORY Tstart = 0.000000
HISTORY Tstop = 0.000000
HISTORY gcudata = no
HISTORY clobber = yes
HISTORY ************************************
END
```

C.2 Response file

Name

ch3_apx_obsOO_mobSS_YYYYMMDD_vX_level2.rsp

File format

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                    8 / number of bits per data pixel
NAXIS   =                    0 / number of data axes
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
MISSION = 'CHANDRAYAAN-3'      / Name of mission/satellite
TELESCOP= 'CH-3_ROVER'         / Name of mission/satellite
INSTRUME= 'APXS    '           / Name of Instrument/detector
ORIGIN  = 'PRLPOC  '           / Source of FITS file
CREATOR = 'apxsgenresp '       / Creator of file
FILENAME= '01_APXXXD32C3R0018000NNNN23237150218004_V5_1.rsp' / Name of file
CONTENT = 'Response File'      / File content
DATE    = '2023-09-20T00:41:40' / Creation Date
END

XTENSION= 'BINTABLE'           / binary table extension
```

```
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   10 / width of table in bytes
NAXIS2  =                 4096 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    3 / number of fields in each row
TTYPE1  = 'CHANNEL '           / label for field   1
TFORM1  = 'I       '           / data format of field: 2-byte INTEGER
TTYPE2  = 'E_MIN   '           / label for field   2
TFORM2  = 'E       '           / data format of field: 4-byte REAL
TTYPE3  = 'E_MAX   '           / label for field   3
TFORM3  = 'E       '           / data format of field: 4-byte REAL
TUNIT1  = '        '           / physical unit of field
TUNIT2  = 'keV     '           / physical unit of field
TUNIT3  = 'keV     '           / physical unit of field
EXTNAME = 'EBOUNDS '           / name of this binary table extension
HDUCLASS= 'OGIP    '
HDUCLAS1= 'RESPONSE'
HDUCLAS2= 'EBOUNDS '
CHANTYPE= 'PI      '           / Channel type
HDUVERS = '1.2.0   '           / OGIP version number
MISSION = 'CHANDRAYAAN-3'      / Name of mission/satellite
TELESCOP= 'CH-3_ROVER'         / Name of mission/satellite
INSTRUME= 'APXS    '           / Name of Instrument/detector
ORIGIN  = 'PRL     '           / Source of FITS file
CREATOR = 'apxsgenresp '       / Creator of file
DETNAM  = '        '
FILTER  = '        '
DETCHANS=                 4096 / Number of channels in ebd
EXTVER  =                    1 / auto assigned by template parser
DATE-OBS= '2023-08-25 13:24:06.587' / Date observation start
DATE-END= '2023-08-25 14:21:20.635' / Date observation end
END

XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   26 / width of table in bytes
NAXIS2  =                 3000 / number of rows in table
PCOUNT  =             49152000 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    6 / number of fields in each row
```

```
TTYPE1  = 'ENERG_LO'           / label for field   1
TFORM1  = 'E       '           / data format of field: 4-byte REAL
TTYPE2  = 'ENERG_HI'           / label for field   2
TFORM2  = 'E       '           / data format of field: 4-byte REAL
TTYPE3  = 'N_GRP   '           / label for field   3
TFORM3  = 'I       '           / data format of field: 2-byte INTEGER
TTYPE4  = 'F_CHAN  '           / label for field   4
TFORM4  = 'J       '           / data format of field: 4-byte INTEGER
TTYPE5  = 'N_CHAN  '           / label for field   5
TFORM5  = 'J       '           / data format of field: 4-byte INTEGER
TTYPE6  = 'MATRIX  '           / label for field   7
TFORM6  = 'PE(4096)'           / data format of field: variable length array
TUNIT1  = 'keV     '           / physical unit of field
TUNIT2  = 'keV     '           / physical unit of field
TUNIT3  = '        '           / physical unit of field
TUNIT4  = '        '           / physical unit of field
TUNIT5  = '        '           / physical unit of field
TUNIT6  = 'cm^2    '           / physical unit of field
EXTNAME = 'MATRIX  '           / name of this binary table extension
HDUCLASS= 'OGIP    '
HDUCLAS1= 'RESPONSE'
HDUCLAS2= 'RSP_MATRIX'
HDUCLAS3= 'FULL    '
CHANTYPE= 'PI      '           / Channel type
HDUVERS = '1.3.0   '           / OGIP version number
MISSION = 'CHANDRAYAAN-3'      / Name of mission/satellite
TELESCOP= 'CH-3_ROVER'         / Name of mission/satellite
INSTRUME= 'APXS    '           / Name of Instrument/detector
ORIGIN  = 'PRLPOC  '           / Source of FITS file
CREATOR = 'apxsgenresp '       / Creator of file
DETNAM  = '        '
FILTER  = '        '
EFFAREA =                   1.
LO_THRES=                   0.
DETCHANS=                4096 / Number of channels in rmf
NUMGRP  =                4096 / Total number of response groups
NUMELT  =                     / Total number of response elements
TLMIN4  =                   0 / First channel number
EXTVER  =                   1 / auto assigned by template parser
END
```

D Example PDS Label for APXS Data Product

Each of the data product of APXS has an associated PDS4 XML label file. An example of the XML label associated with a raw science data file of APXS is given here. All other product labels also have a similar structure.

```
<?xml version="1.0" encoding="UTF-8"?>
<?xml-model href="https://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1700.sch"
  schematypens="http://purl.oclc.org/dsdl/schematron"?>
<Product_Observational xmlns="http://pds.nasa.gov/pds4/pds/v1"
xmlns:pds="http://pds.nasa.gov/pds4/pds/v1" xmlns:disp="http://pds.nasa.gov/pds4/disp/v1"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://pds.nasa.gov/pds4/pds/v1
https://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1700.xsd
http://pds.nasa.gov/pds4/disp/v1 https://pds.nasa.gov/pds4/disp/v1/PDS4_DISP_1600.xsd">
    <Identification_Area>
        <logical_identifier>
                  urn:isro:isda:ch3_chr:apx_calibrated:obs01_mob02_20230825_lunobs
        </logical_identifier>
        <version_id>1.0</version_id>
        <title>Chandrayaan-3 Rover APXS Experiment</title>
        <information_model_version>1.11.0.0</information_model_version>
        <product_class>Product_Observational</product_class>
        <Modification_History>
            <Modification_Detail>
                <modification_date>2024-02-16</modification_date>
                <version_id>1.0</version_id>
                <description>Created by APXS POC PRL</description>
            </Modification_Detail>
        </Modification_History>
    </Identification_Area>
    <Observation_Area>
        <Time_Coordinates>
            <start_date_time>2023-08-25T13:30:36.795Z</start_date_time>
            <stop_date_time>2023-08-25T14:15:08.931Z</stop_date_time>
        </Time_Coordinates>
        <Primary_Result_Summary>
            <purpose>Science</purpose>
            <processing_level>Calibrated</processing_level>
            <description>
        A series of multiply defined digital objects.
      </description>
        </Primary_Result_Summary>
        <Investigation_Area>
            <name>Chandrayaan-3</name>
            <type>Mission</type>
            <Internal_Reference>
                <lidvid_reference>urn:isro:isda:context:investigation:mission.chandrayaan3::1.0
                </lidvid_reference>
                <reference_type>data_to_investigation</reference_type>
```

```
        </Internal_Reference>
    </Investigation_Area>
    <Observing_System>
        <name>Observing System</name>
        <Observing_System_Component>
            <name>Chandrayaan-3 Rover</name>
            <type>Spacecraft</type>
            <description>
        The rover of Chandrayaan-3 mission, named as Pragyan, carried out in-situ exploration
        in the vicinty of the landing site.
    </description>
        </Observing_System_Component>
        <Observing_System_Component>
            <name>Alpha Particle X-ray Spectrometer</name>
            <type>Instrument</type>
            <description>
    Alpha Particle X-ray Spectrometer (APXS) is one of the two experiments on-board Chandrayaan-3
    Rover to perform in-situ elemental abundance measurements. APXS accomplishes this by measuring
    intensities of characteristic X-rays emitted by the constituent elements of the lunar surface
    due to the processes known as Particle Induced X-ray Emission (PIXE) and X-ray Fluorescence (XRF).
    X-ray and Alpha radiation from the Cm-244 radioactive sources included in APXS excites the elements
    to generate characteristic X-ray lines. The Silicon Drift Detector (SDD) at the heart of
    the instrument measures this X-ray spectrum in the energy range of 0.8 - 25 keV with high
    resolution (135 eV at 5.89 keV) enabling identification of each major element uniquely.
    </description>
        </Observing_System_Component>
    </Observing_System>
    <Target_Identification>
        <name>Moon</name>
        <type>Satellite</type>
        <description>
    Moon is the natural satellite of the Earth.
  </description>
    </Target_Identification>
</Observation_Area>
<File_Area_Observational>
    <File>
        <file_name>ch3_apx_obs01_mob02_20230825_lunobs_v1_level2.pha</file_name>
        <local_identifier>file</local_identifier>
        <creation_date_time>2024-02-16T11:30:40</creation_date_time>
        <file_size unit="byte">74880</file_size>
        <records>4096</records>
        <md5_checksum>e881f1dd5907ec9a8d1370dc7f398fed</md5_checksum>
    </File>
    <Header>
        <local_identifier>header_Primary</local_identifier>
        <offset unit="byte">0</offset>
        <object_length unit="byte">2880</object_length>
        <parsing_standard_id>FITS 3.0</parsing_standard_id>
    </Header>
    <Header>
        <local_identifier>header_Spectrum</local_identifier>
        <offset unit="byte">2880</offset>
```

```
            <object_length unit="byte">5760</object_length>
            <parsing_standard_id>FITS 3.0</parsing_standard_id>
        </Header>
        <Table_Binary>
            <local_identifier>data_Spectrum</local_identifier>
            <offset unit="byte">8640</offset>
            <records>4096</records>
            <description>The records count is the number of rows in this table</description>
            <Record_Binary>
                <fields>4</fields>
                <groups>0</groups>
                <record_length unit="byte">16</record_length>
                <Field_Binary>
                    <name>CHANNEL</name>
                    <field_location unit="byte">1</field_location>
                    <data_type>SignedMSB4</data_type>
                    <field_length unit="byte">4</field_length>
                    <unit>DN</unit>
                    <description>Channel of X-ray Spectrum</description>
                </Field_Binary>
                <Field_Binary>
                    <name>COUNTS</name>
                    <field_location unit="byte">5</field_location>
                    <data_type>IEEE754MSBSingle</data_type>
                    <field_length unit="byte">4</field_length>
                    <description>Counts for corresponding channels</description>
                </Field_Binary>
                <Field_Binary>
                    <name>STAT_ERROR</name>
                    <field_location unit="byte">9</field_location>
                    <data_type>IEEE754MSBSingle</data_type>
                    <field_length unit="byte">4</field_length>
                    <description>Statistical error in counts</description>
                </Field_Binary>
                <Field_Binary>
                    <name>SYS_ERROR</name>
                    <field_location unit="byte">13</field_location>
                    <data_type>IEEE754MSBSingle</data_type>
                    <field_length unit="byte">4</field_length>
                    <description>Systematic error in counts</description>
                </Field_Binary>
            </Record_Binary>
        </Table_Binary>
    </File_Area_Observational>
</Product_Observational>
```