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IMAGING X-RAY POLARIMETRY EXPLORER (IXPE)

Science Data Management Plan

Revision B

2019-Sep-22

DOCUMENT CHANGE LOG

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Revision	A	08/09/2018	Clarify HEASARC data release
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1 INTRODUCTION

1.1 Plan Purpose and Scope

This document defines the plan for the Imaging X-ray Polarimetry Explorer (IXPE) data processing, data management, and data archiving system, which is effective after the data is delivered to the Science Operations Center (SOC) at NASA Marshall Space Flight Center (MSFC) from the Mission Operations Center (MOC) at the University of Colorado Laboratory for Atmospheric and Space Physics (LASP). This plan describes how the mission will meet the science requirements that address the preparation, distribution, and archiving of processed science data for the general community.

Expected readers of this document are members of the IXPE Project Office, program managers at NASA HQ, members of the IXPE development and operations team, and IXPE data users.

Readers are reminded that this document does not serve as the original source for technical information such as instrument specifications and telemetry formats, or high-level agreements. These technical and/or programmatic issues are defined and documented in the original documents maintained by the IXPE Project Office and NASA HQ.

1.2 Relationship to Other Documents

This document summarizes and refers readers to information contained in several other documents. The information contained in this document is intended to be generally accurate; however, some documents referred to by this document are evolving works, and those documents supersede this document in case of a conflict.

Other documents referred to by this document:

IXPE-RQMT-009-L1-01	IXPE Project Requirements Document
IXPE-RQMT-009-L3-02	IXPE Science Operations Center (SOC) Specification
IXPE-ADP-036	ICD-Mission Operation Center (MOC) to Science Operations Center (SOC)
IXPE-ICD-037	ICD-Science Operation Center (SOC) to (HEASARC)

2 MISSION OVERVIEW

2.1 Overview

IXPE is an Astrophysics Small Explorer (SMEX) mission dedicated to the measurement of X-ray polarization. IXPE will conduct X-ray polarimetry from many categories of cosmic X-ray sources, including neutron stars, stellar-mass black holes, supernova remnants, and active galactic nuclei.

For the brighter extended sources—such as Pulsar Wind Nebulae (PWNe), Supernova Remnants (SNR), and large-scale jets in Active Galactic Nuclei (AGN)—IXPE will perform X-ray polarimetric imaging.

These polarization measurements will help answer fundamental questions:

* What are the geometries of the flows, emission regions, and magnetic fields?
* What physical processes lead to particle acceleration and X-ray emission?
* What are the physical effects of gravitational, electric, and magnetic fields at their extreme limits?

IXPE achieves these goals using three co-aligned X-ray telescopes mounted on a 3-axis stabilized spacecraft. Each telescope comprises a Mirror Module Assembly (MMA), manufactured at MSFC, and a Detector Unit (DU), provided by the Italian partners. The mirrors and detectors are mounted on a boom that extends after launch. The grazing-incidence mirrors composed of nickel/cobalt shells, have a 4-m focal length and image onto three polarization-sensitive Gas Pixel Detectors (GPD).

IXPE will be launched to an equatorial Low-Earth Orbit (LEO), which provides a stable, low-background environment. Data are stored onboard and routinely dumped through the Malindi ground station. The MOC will monitor the observatory performance during the pass and then collect the dumped data. The MOC will then produce files containing the raw telemetry data, which are passed to the SOC. The MOC also converts the engineering and housekeeping data into physical units, which are also passed to the SOC. The SOC converts these files into Flexible Image Transport System (FITS) format for long term archiving at the High Energy Astrophysics Science Archive Research Center (HEASARC).

2.2 Operations Concept

The SOC will collect a list of proposed science targets and required calibration observations. The SOC will then lay out a long-term plan that meets observing constraints. About 3 weeks prior to an observation, the SOC will inform the MOC of the anticipated data load for that week. This will allow the MOC to schedule additional contacts for weeks with high data load (such as observing the Crab Nebula) or fewer contacts if lower-count-rate sources are expected.

One week prior to the observations, the SOC will produce an Instrument Activity Plan (IAP) that lists the precise targets and/or calibrations that should be done in the coming week. The MOC will lay out a detailed mission time line that includes all spacecraft operations such as slews and data dumps. This plan will be made available to the SOC for concurrence.

During the week, the MOC handles all the spacecraft/detector commanding and monitors the observatory health and safety and data-storage usage. The MOC collects the dump data, which it passes to the SOC. The dump data will include both the science data from the instrument and all the engineering data from the observatory. By routine processing of the science data, the SOC will monitor instrument performance. This will include items such as monitoring the gain and searching for dead pixels.

2.3 IXPE Detector Data

As the IXPE detectors operate slightly differently from previous X-ray detectors, we briefly describe the detector and data produced. X rays enter the detector and interact in a gas volume producing an electron. The initial direction of this photoelectron track contains information about the electric field direction (polarization) of the X ray. However, as the electron loses energy (through collisional ionization of the detector gas), it can scatter significantly before it stops. Thus, the detector must be able to resolve the initial direction of the electron from the rest of the track. This is done by producing a 2D image showing the collected charge on a lattice of hexagonal pixels. On-board processing will suppress low values (background noise) and compress the image before it is sent to the ground. These images will have a variable size that partly depends upon the photon energy.

Bright sources will require special handling. For example, a 1.6-day exposure on the Crab Nebula is expected to generate about 16 GB of data on the spacecraft. There is about 4 GB available on-board storage and only about 0.7 GB can be dumped in a day. This necessitates an observing strategy whereby the Crab Nebula observation will be divided into 4 observing segments of 0.4 day (filling the on-board storage) spaced about a week apart. Between the Crab observation segments, IXPE will observe fainter sources until all the data from the previous Crab observation segment have been downloaded.

The Italian team that developed the detector has also developed a simple and robust algorithm that determines the initial electron direction. The SOC will make maximal use of existing algorithms and software when processing the detector data.

The track images will be stored as a variable-record-length FITS file. For the Crab example, the unpacked track images could contain up to 100 GB. Due to this large data volume, only level-1 data products will contain track data.

2.4 Definition of Processing Levels

Level-0 (L0) data are raw CCSDS telemetry packets collected into files by the MOC. These files along with daily shift reports are then transferred to the SOC. Housekeeping data from both the spacecraft and instrument, instrument science data, and star-tracker data are included.

Level-1 (L1) data contains everything: the telemetry packets have been unpacked, time-ordered, any duplicates deleted, and the results converted into FITS files. The L1 data are unfiltered; thus, for example, event files will include all events in a given pointing (or slew), which may include data from the source, data in the South Atlantic Anomaly (SAA), data when pointed at the Earth, etc.

Level-2 (L2) data contain clean data that have been time filtered to include only data from Good Time Intervals (GTI) when the detector was exposed to the source. In addition, relevant calibrations have been applied: Positional data will have been converted to J2000 sky coordinates, etc. To reduce the size of downloads, the L2 data files will include the initial track direction but will not contain track images.

Level-3 (L3) data products are application specific. Examples are source maps, catalogs of source positions and fluxes, and light curves. These products are produced and documented by the SOC. The goal of L3 is to produce data products using a standard processing method. The precise definition of background levels and energy cuts will be decided after launch with inputs from the science community.

The pipeline will produce intermediate products that can be used to test the operation. As these intermediate products will not be archived at the HEASARC, they are not identified in this document. All the tools to produce these intermediate products will be provided to the HEASARC as part of the IXPE ftools sub-package.

If users are content with the standard processing, which includes track analysis, they can start with L2 files and use existing tools to select, plot, and analyze events. Users who want to redo the track analysis (perhaps with a new algorithm) will need to start with L1 data.

2.5 Science Support

The SOC will ingest the PI-approved target list and generate a long-term Plan (LTP). This schedule will meet basic spacecraft requirements such keeping the solar panels pointed near the Sun and mixing high and low count rates sources to not overflow the onboard storage. After commissioning, the LTP will be made available on the IXPE web server and mirrored at the HEASARC. On a weekly basis, the SOC will provide the MOC with the Instrument Activity Plan (IAP) that contains the near-term observing plan.

The SOC will be retrieve data from the MOC and generate L1 and L2 data products. Some of these products will be made available on a local web server. The SOC will also maintain a local archive containing mission data, calibration database and observation catalog. The SOC will interface with the HEASARC where the science products, documentation, and relevant software will be archived.

The SOC will also work with the Italian team, which will provide data-processing algorithms and software. In particular the Italian institutes will contribute to the following SOC activities:

- Instrument telemetry parsing (formatting of the telemetry packets in FITS) and conversion into physical units: contribution from INAF-OAC;
- Providing algorithms for the reconstruction of the photoelectron track: contribution from INFN and INAF-IAPS;
- Engineering of IXPE reconstruction software in the HEASoft package ("IXPE FTOOLs"): contribution from the Space Science Data Center (SSDC– ASI);
- Providing ground calibration data: contribution from INAF-IAPS and INFN;
- Supporting the IXPE CALDB (HEASARC standard): contribution from SSDC-ASI.

The functions of the IXPE SOC may be summarized as follows:

- Ingest algorithms, software, and calibration data from the Italian team
- Lay out a long-term schedule that meets science and calibration requirements and observing constraints
- Deliver the Instrument Activity Plan (IAP) to the MOC as needed
- Review the Mission Timeline Report produced by the MOC to make sure it meets the science goals
- Receive L0 science and engineering data from the MOC
- Make data available to our Italian partners
- Produce daily L1 data files in FITS format
- As needed, cut and merge L1 files to produce L1 files by target
- Produce L2 data files by target
- Deliver data products to the HEASARC permanent archive, using the delivery methods, formats and schedule agreed in the SOC-HEASARC ICD
- Deliver all calibration data and software necessary to produce L2 and higher level data to HEASARC archive, using the delivery methods, formats and schedule agreed in the SOC-HEASARC ICD
- Support the development of L3 products
- Produce L3 products and deliver to the HEASARC
- Document the SOC system
- Maintain a catalog of all available data.

3 DATA PROCESSING

3.1 Data Processing Flow

The MOC will produce dump files that contain the raw telemetry data from both the instrument and spacecraft. These files may contain gaps due to telemetry dropouts and/or duplicate data to fill in gaps from a previous pass. These files are then copied to the SOC. In addition to the raw packets, the MOC will also produce files that contain the spacecraft/housekeeping data converted into engineering units. During the initial 3-month checkout, these files will be made available shortly after they appear at the MOC. During normal operations, this may be reduced to once per day.

The SOC will use the MOC-converted engineering data to produce the L1 FITS files of the engineering data. Using these files will ensure the MOC and SOC are using a common set of units (and telemetry tables).

The science data packets are unpacked by the SOC. These are then converted into FITS format, per the SOC-HEASARC ICD. In addition to formatting, L1 processing includes those data processing steps which are reversable and can be understood, defined, and coded before launch, and do not require iterated processing with increasing experience. Examples of such steps include decompression of compressed data, and conversion of spacecraft clock timestamps to terrestrial time (TT).

Receipt of new L0 data at the SOC will trigger an ingest process at the SOC, where the data are added to the L0 data inventory, and the star tracker and orbit data are added to the attitude-orbit database. These data will be made available to our Italian partners.

Once the ingest process has completed, the new data are converted to L1 FITS format, and added to the archive of L1 data at the SOC. Upon successful completion of the conversion to L1, the new L1 data are delivered to the HEASARC per the SOC-HEASARC ICD and the level 1 requirements

Intermediate products are built from the L1 data products. An example of an intermediate product could contain track data where each pixel has been gain-corrected. Since the track images are fairly large and the gain correction very straight forward, we shall not archive the intermediate products, but always reconstruct them from the L1 files. However, intermediate products will be used to validate the functioning of the pipeline.

L2 products combine processed science data with aspect and calibration data to produce an event list consisting of a Right Ascension and Declination, calibrated energy, arrival time and initial track direction for each X ray to produce L2 FITS files. These files will conform to HEASARC standards and are described in the SOC-HEASARC ICD.

L2 data processing is triggered by the production of new L1 data. L2 processing requires data processing algorithms/software and up-to-date calibration data. When calibrations are updated the SOC performs an ingest process by which the update is incorporated into the production data processing pipeline software, and any necessary L2 data reprocessing is performed. The SOC then delivers the new software/database to the HEASARC, after a period of software testing and verification.

L3 data will be produced by the SOC and provided to the HEASARC for archiving and distribution. The format of these products will be described in the SOC-HEASARC ICD. If appropriate for a particular L3 data product, software for the production of that product from lower-level data will also be provided and documented.

Calibration data products are produced by the SOC and used in L2 data processing in the form of a calibration data base (CALDB). All calibration data files made available by the SOC will be in FITS format and will conform to the HEASARC CALDB standard as detailed in the SOC-HEASARC ICD.

All calibration data files and software tools required for generating instrument response will be delivered to the HEASARC prior to launch and updated as needed.
The IXPE science team will produce science images sufficient for outreach purposes within one month of on orbit checkout and calibration.

All data files required for analysis of the IXPE science data will be delivered to the HEASARC within one week of production. Once an observation has been completed and validated, the data will be accessible to the broader astrophysical community immediately through the HEASARC with no proprietary period, as described in section 3.5

The final, fully calibrated IXPE science data set shall be delivered to the HEASARC within one year following the end of the mission.

3.2 Data Volume and Data Distribution

Data will be distributed by the HEASARC.

Based on an analysis of our Design Reference Mission the average dump rate will be 370 MB/day. The best we can do is dump every pass. This gives 14 passes * 600 sec/pass * 2 Mb/sec * 1B/8b * 0.76 = 1600 MB/day where 0.76 is a transmission efficiency factor that estimates the data losses due to nulls in the antenna beam pattern.

For L1 we will unpack the track images by putting zero in place of data that was not transmitted. This greatly increases the uncompressed file size. However, a file rich in integer zeros can be efficiently compressed. Thus, the required storage space will be about a factor 3 larger than the L0 data. This gives 1200 MB/day with a peak of 4800 MB/day.

For L2 data without the track images, the volume greatly decreases. For this we estimate 100 MB/day with a peak of 450 MB/day.

3.3 Data Formats, Documentation, and Technical Support

All L1 and L2 data files produced by the SOC will be in FITS format, per the guidelines issued by the HEASARC FITS Working Group (HFWG), and as detailed in the SOC-HEASARC ICD.

All calibration data files produced by the SOC will be in FITS format and will conform to HEASARC CALDB standard as detailed in the SOC-HEASARC ICD.

The SOC is responsible for producing a Science Data Users Guide for analyzing IXPE data and for delivering it to the HEASARC. This Users Guide will be considered to be part of the software.

3.4 Software Deliverables

The SOC will deliver all software tools required for production of L2 data and analysis of the IXPE data to the HEASARC.

All data processing software delivered by the SOC to the HEASARC will conform to FTOOLS standards as detailed in the SOC-HEASARC ICD.

3.5 Data and Software Verification and Delivery Schedule

A level 1 requirement states that for the first three months of the mission, all IXPE data shall be made publicly available at the permanent science data archive within 30 days of the end of an observation. The end is defined to be when 90% of the data has been collected. After the first 3 months, data shall be made available within 1 week of the end of an observation.

During the baseline mission, the SOC will deliver L1 and L2 data products to the HEASARC immediately after processing. Per standard practice, the HEASARC will encrypt these data for a limited time, during which the SOC will perform basic verification of data quality. This encryption period shall be consistent with requirements stated in the previous paragraph for public availability of the data. By the end of this period, the HEASARC can decrypt and thus release the data. During an optional mission extension, the data shall remain encrypted for the proprietary period and access provided to the respective General Observer.

Preliminary versions of the L2 data processing software and calibration databases will be delivered to the HEASARC prior to launch and updated shortly after commissioning. There will be additional updates as needed throughout the life of IXPE.

4 DATA ARCHIVING AND PRESERVATION

4.1 L0 Data Archiving at the MOC

The MOC archives all L0 data products for the life of the mission plus one year, as well as all telemetry data and support data products, per the MOC Level 3 Requirements document.

4.2 SOC Local Archive

The SOC archives all L0, L1, L2, calibration, and higher-level data products for the life of the mission plus one year, as well as all support data products, and all data processing software. The SOC will backup data nightly to an external drive in a different room.

4.3 HEASARC Archive

All IXPE L1, L2, calibration, and higher-level data, as well as the software and calibration data required for producing these products from the L1 data, will be archived at the HEASARC according to established HEASARC archiving practices.