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ASTRI SST-2M archive system: a prototype for the Cherenkov Telescope Array

Alessandro Carosi[a,b], Stefano Gallozzi[a], Fabrizio Lucarelli[a,b], Saverio Lombardi[a,b], Michele Mastropietro[a,b], Lucio Angelo Antonelli[a,b], Alessandro Costa[c], Alberto Madonna[a,d], for the ASTRI Collaboration[e], and the CTA Consortium[f]

[a]INAF Osservatorio Astronomico di Roma, Monte Porzio Catone, Italy
[b]ASI Science Data Center, Rome, Italy
[c]INAF, Osservatorio Astronomico di Catania, Catania, Italy
[d]GPU Research Center, University of Padova, Italy
[e]http://www.brera.inaf.it/astri/
[f]http://www.cta-observatory.org/

ABSTRACT

The ASTRI project of the Italian National Institute for Astrophysics (INAF) is developing, in the framework of the Cherenkov Telescope Array (CTA), an end-to-end prototype system based on a dual-mirror small-sized Cherenkov telescope. Data preservation and accessibility are guaranteed by means of the ASTRI Archive System (AAS) that is responsible for both the on-site and off-site archiving of all data produced by the different subsystems of the so-called ASTRI SST-2M prototype. Science, calibration, and Monte Carlo data together with the dedicated Instrument Response Functions (IRFs) (and corresponding metadata) will be properly stored and organized in different branches of the archive. A dedicated technical data archive (TECH archive) will store the engineering and auxiliary data and will be organized under a parallel database system. Through the use of a physical system archive and a few logical user archives that reflect the different archive use-cases, the AAS has been designed to be independent from any specific data model and storage technology. A dedicated framework to access, browse and download the telescope data has been identified within the proposal handling utility that stores and arranges the information of the observational proposals. The development of the whole archive system follows the requirements of the CTA data archive and is currently carried out by the INAF-OAR & ASI-Science Data Center (ASDC) team. The AAS is fully adaptable and ready for the ASTRI mini-array that, formed of at least nine ASTRI SST-2M telescopes, is proposed to be installed at the CTA southern site.

Keywords: Very High Energy Astrophysics, Imaging Atmospheric Cherenkov Telescopes, CTA, ASTRI, Data Archive

1. INTRODUCTION

The improvement of our comprehension of astronomical sources during the last few decades is strictly connected to the progresses in the observations at different wavelengths. At present, new instruments and technologies make almost the entire electromagnetic spectrum accessible to our investigation. Within this context, high energy (HE; $E \gtrsim 50$ MeV) and very high energy (VHE; $E \gtrsim 50$ GeV) astrophysics have played the most important role in changing our prospective of astrophysics research. Depending on their energy, the detection of HE and VHE γ photons can be done using both a *direct* technique (i.e., through the detection of the primary γ-ray outside the Earth's atmosphere with space-based instruments) and an *indirect* procedure. The latter involves the study of the secondary products (both radiation and particles) generated in the primary γ-ray-induced atmospheric shower with ground-based telescopes. Currently, the VHE sky is being investigated with large collection areas by means of ground-based imaging atmospheric Cherenkov telescopes (IACTs), such as H.E.S.S,[1] MAGIC,[2] and VERITAS.[3]

Send correspondence to Alessandro Carosi (E-mail: alessandro.carosi@oa-roma.inaf.it)

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The view of the VHE sky provided by these telescopes has revealed an unexpected richness and complexity of phenomenology leading to the discovery of more than 150 new sources. In the near future, a new generation of instruments, will play a key role in our comprehension of VHE sources. Now still in a design phase, the future *Cherenkov Telescope Array*[4] will increase the sensitivity by a factor ~ 10 compared to current telescopes, and it will enlarge the energy domain from a few tens of GeV to hundred of TeV with unprecedented angular and energy resolution. The CTA consortium foresees the construction of several tens of Cherenkov telescopes. They will be arranged in two arrays, one placed in the northern hemisphere and the other in the southern hemisphere, so that the whole sky is covered. In the current layout of the CTA project, the arrays will consist of three types of telescopes with different mirror sizes in order to cover the full accessible energy range. Furthermore, in contrast to the current installations, CTA will be open to the entire astrophysics community, operating as a proposal-driven observatory. The construction of the first elements of CTA is expected to begin in 2018.

Within the framework of CTA, the ASTRI SST-2M prototype is a dual-mirror, small-sized, end-to-end Cherenkov telescope developed by the Italian National Institute for Astrophysics (INAF). The prototype is under integration at the INAF observing station of Serra La Nave (Mt. Etna, Italy). The ASTRI SST-2M prototype is characterized by a wide-field dual-mirror Schwarzschild-Couder optical design and by an innovative Silicon photomultiplier (SiPM) camera managed by very fast read-out electronics. A detailed description of the ASTRI SST-2M prototype is provided in Ref. 5 and Ref. 6. Preservation and accessibility of the data are guaranteed by the ASTRI archive system (AAS) that is designed to be compliant with the CTA requirements. It will also serve as a test-bench for the ASTRI mini-array,[7] a collaborative effort led by INAF and carried on by institutes from Italy, Brazil, and South-Africa.

1.1 The ASTRI Archive System

1.2 Software framework

The FITS format[8] has been adopted for the *scientific* data produced by the ASTRI SST-2M prototype. HEASARC-NASA `cfitsio` libraries[9] are used for FITS read/write, checksum/verification and basic manipulation of data. The programming language used for AAS is standard-ANSI C while a few modules will be interfaced by means of python wrappers and libraries. The current database software server is based on the relational Mysql [*] V. 14.14, distribution 5.5.40 for Debian-linux-gnu (x86_64) systems.

The AAS Data model is currently mapped using a well balanced mixture of relational and non-relational databases (mySQL for the storage part and mongoDB for the logging part). As the ability to extract information from operational data is critical for our system we are planning the full migration of the whole ASTRI data model from a relational approach to a NoSQL database during the second forthcoming step of the project, the ASTRI mini array. This approach, beside being scalable and efficient, is also engineered for real time big data. MongoDB[10] and also couchbase[11] are suitable implementations of NoSQL DBs. The already implemented MongoDB testbed has been proven to provide better performances for scalability and optimization related to big data entry records of log instances in comparison with a relational DB. Nevertheless, the use of couchbase system is currently under investigation. It has been suggested that this DB could provide higher benchmark performance than mongoDB based solutions[12] and analysis of its performance within the ASTRI framework is ongoing.

1.3 ASTRI data model

The main data levels (DL) of the ASTRI SST-2M prototype (as well as for the mini-array) have been defined in order to be compliant with the foreseen data model of the CTA although some specific intermediate sub-data levels have been adopted. A full description of the ASTRI DL is provided in Ref. 6 and can be summarized as follows:

[*] Structured Query Language

- **DL0:** *RAW* - these are the data written to disk by the Data Acquisition component (DAQ)
- **DL1:** *telescope-wise* - reconstructed parameters: energy, direction and particle identification
- **DL2:** *array-wise* - reconstructed parameters: energy, direction and particle identification
- **DL3:** *reduced* - set of selected (e.g., γ-ray) events and corresponding instrument response function (IRF)
- **DL4:** *science* - high-level data products (spectra, sky-maps, light-curves)
- **DL5:** *observatory* - final products of the Observatory such as survey sky-map and source catalog.

The ASTRI data flow and the corresponding data reconstruction and scientific analysis needed for the productions of the different DLs is described in Ref. 6. Furthermore, besides event-list data type (EVT) of different levels, the full ASTRI data flow involves the use of specific Monte Carlo (MC) simulations as well as calibration (CAL) and engineering & auxiliary information (TECH data). Furthermore, a limited subset of TECH data that are needed by the scientific analysis (pointing information, camera housekeeping and weather monitor parameters) feeds the reconstruction pipelines (SciTECH)

According to current specifications, the expected data (EVT+CAL+TECH/SciTECH) size for ASTRI is:

- $\sim$ 10 kB/(science event)
- $\sim$ 500 Hz of nominal data acquisition rate
- $\sim$ 8 hours of observation/night ($6 \div 10$)

This should account for a total expected data amount of $\sim$0.8 TB/night (that will increase to about 3 TB/night in the case of the mini-array). In Tab.1,

Table 1. Expected data size for each data level for the ASTRI prototype. * DL1 is intended as the sum of three sub data levels (DL1a, DL1b, DL1c) as described in Ref. 6

Data Level	**TB/night**
DL0 (RAW EVT+CAL+TECH)	0.2
DL0 (FITS EVT+CAL+SciTECH)	0.2
DL1 (tel-wise)	0.4^*
DL2 (array-wise)	0.002
DL3 (reduced)	0.0002
DL4 (science)	$\lesssim$0.0002
DL5 (observatory)	$\lesssim$0.001

1.4 AAS Functional Design

Within the CTA framework, three levels of archive prototypes are going to be developed:

- LEV-A: the first prototype of the CTA archive. It will organize all relevant data products coming from the ASTRI SST-2M prototype. The ASTRI archive system will provide full access to several archive users to all the data set in order to acquire, reduce, analyse and publish scientific data in a PI-oriented platform.
- LEV-B: this second level of the archive system prototype can efficiently manage (for archiving and data-precessing activities) all data coming from several telescopes with (possibly) different kinds of camera technology (mini-array).

- LEV-C: CTA Archive core. It is the final prototype version envisaged to be totally compliant with CTA requirements.

The AAS will provide the archive facility for all the product of the ASTRI SST-2M prototype observatory from the RAW data level (DL0) up to the final products (DL5). A dedicated technical data archive (TECH archive) will store the telescope engineering and auxiliary data and will be organized under a parallel database system using the Telescope Monitor and Configuration Database (TMCDB) within the Alma Control system (ACS) framework.[13]

The AAS architecture has been designed to be adaptable to different archive use cases being, at the same time, independent of any specific data model and storage technology. To this end, the realization of the archive architecture has been developed using a *physical* system archive and a few logical *user* archives: the latter reflect the organization aligned to the use-cases foreseen for the different archive users.

- *System Archive:* it represents the RAW data files repository. A dedicated archive daemon moves the files to the storage media and orders them according to their origin and creation date.
- *User Archive(s):* they have a file-system structure with directory tree based on file tags creating symbolic links to the files stored in the system archive.

The main advantage of having such a double-structured archive is the possibility of separating the hardware physical side of the archive from its logical structure, which can reflect different user-driven data organizations. Thus, archive hardware components will be independent of any particular data model and database technology. Furthermore, the AAS has been developed in order to be expandable in terms of storage capability and data rate acquisition without incrementing the overall CPU consumption time. Thus, with the increasing number of operating telescopes, the AAS will still fulfill the pre-production mini-array requirements.

1.5 AAS daemon

The ingestion of the data within the archive is performed by means of a dedicated "ASTRI Archive Daemon" (AAD). The AAD is responsible for checking the specific repository to search for new files of different origin i.e., RAW DL0 data from camera data-flow, intermediate and higher level products from MC and scientific data reduction pipelines, engineering and auxiliary files from slow control monitoring and TMCDB system.

The AAD is an ANSI-C program which interfaces with `cfitsio` libraries[9] and uses threads to perform parallel computations (tested up to 120 simultaneous computations). The AAD performs the following steps:

- polling a directory to search for new files
- parsing the file name (for DL0 data), and performing a checksum/verification and crosscheck with FITS header keywords (only in case of FITS files)
- creating a permanent storage directory and moving files there with their Physical File Name notation (PFN)
- creating a Logical File Name notation (LFN) for the physical files and symbolically linking the files to a customized logical path
- ingesting all information related to the file in a dedicated database table, according to the ASTRI Scientific Data Model (ASDM)
- saving log information in a dedicated database

1.6 System Archive

The "system archive" is the physical repository for the data. It presents a minimal hierarchy and organization of data where the physical files are stored according to the ASTRI specific naming convention. Files are stored according to their origin and are ordered by creation date.

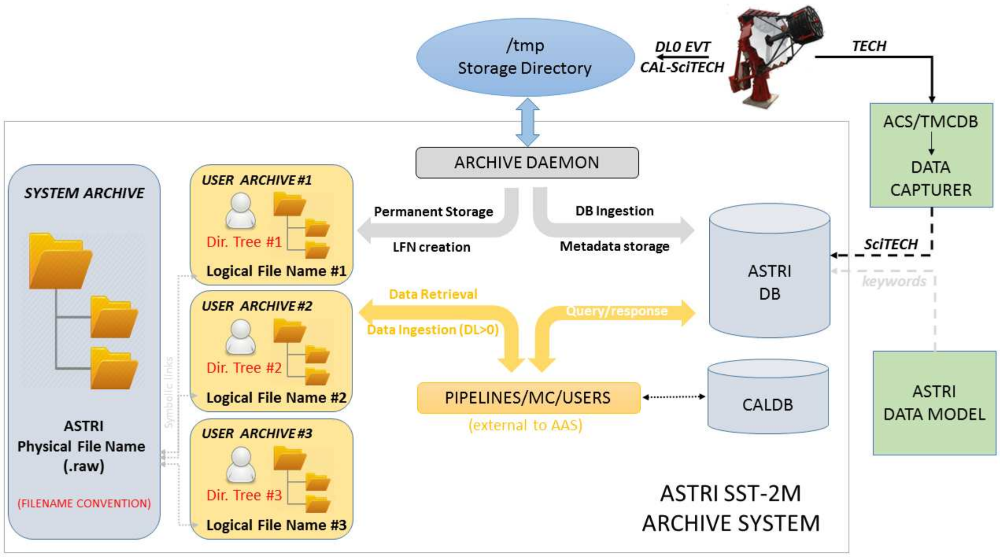

Figure 1. The ASTRI Archive Daemon is the central component in the diagram. It provides all the logic of the archive permanent storage and produces the logical file notation for the different ASTRI archive users.

1.7 User Archives

It has a file-system structure with a directory tree based on file tags creating symbolic links to the files stored in the system archive. Within the ASTRI SST-2M framework, three main "users" have been identified for the various archive organizations:

- The **pipeline** user: the data reduction pipelines are the main instrument for manipulating and processing the ingested files in order to create DLn (n> 0) data. Particular attention has been given to organize the logical structure of this archive in order to provide efficient I/O to improve the performance of the internal on-site system.
- The **MC Simulation** user: Monte Carlo simulations are of fundamental importance for the γ-ray event reconstruction process. A dedicated DB is foreseen in order to cope with the different MC productions. The physical file name notation is the same one adopted for real data with some keywords reallocated to map the different MC productions.
- The **Principal Investigator (PI)** user: the user archive identified for the Principal Investigators is strictly connected to the data retrieval and PI user access utility. In this logical structure the symbolic links are replaced by a database structural view aggregated by the Proposals&Observing program blocks.

1.8 Archive log & alarm

All operations involved in the ASTRI archive runtime will be traced in order to monitor and track the system integrity. Each module of the Archive (i.e. the ingestion program daemon) is logged to a dedicated MongoDB collection. The schema-less configuration of Mongo collections permits the aggregation of all logged pieces of information depending on the verbosity setting. If the program exits successfully, the log entry document will store only the time-stamp of the related file name (logical and physical) and a description of the operation involved. On the other hand, if some errors or warnings occur, the logging document will be filled with extra information to facilitate issue troubleshooting.

2. ARCHIVE DATABASE

As a crucial aspect of the ASTRI archive system, an efficient database management system (DBMS) has been developed. The ASTRI DBMS will accept data requests (queries) only by the authorized AAS users allowing the transfer of the appropriate data from the archive's storage volumes. The current development of the ASDM is intended to be independent of the chosen DB paradigm in order to easily switch between the SQL engine and a NoSQL engine at any particular phase of the CTA production.

Three main levels of DBs are identified within the AAS framework:

- **Scheduler and proposal handling DB**. It is intended to describe how the observations are organized, ranked, planned and scheduled. It will allow the Guest Observer to retrieve the basic information as well as the status of the submitted proposal. By means of this DB, the Guest Observer may be informed about the proposal ranking, the observations planning and the telescope's schedule. The database structure is transferred, on a daily base, to the ASTRI Scheduler program in the Operator Control System (OCS) using a dedicated JSON structured data query to be finally scheduled for the observation.
- **Archives DB**. It is intended to describe how the observations are performed, stored, reduced, analysed, linked together and published for the final user. It will allow ASTRI users to browse archive branches (including MC & pipelines branches) according to how the observations were performed, stored, analyzed and, eventually, linked together.
- **Technical, engineering & monitoring DB**. It will permit the retrieval of the TECH data describing the status of the different ASTRI subsystems including real configurations, alerts and auxiliary information needed for health and slow control monitor status of the system (with acquisition frequency between 0.1-1 Hz). It will be managed by means of the ACS TMCDB. Furthermore, a periodic subset of technical monitoring information will feed the data reduction.

A further DB, the **CALibration DataBase (CALDB)**, is envisaged. It is a special dedicated database module to feed pipelines throughout the scientific data reduction (involving DL1, DL2 and DL3 data). This particular database is a collection of calibration files (organized in directory trees) dedicated to specific aspects of the calibration procedure[6] (related to the instrumental configuration and response function). The first implementation of such an archive was done using the HEASARC's calibration database,[14] which is a public system to store, organize and index datasets associated with calibration of high energy astronomical instruments of different space missions.

3. CONCLUSION

The ASTRI SST 2M archive system has been designed to store and preserve all the data produced during the ASTRI prototype operations. The archive system was conceived to be independent of the specific data model and storage technology. To this end, a physical system archive and a few logical user archives that reflect the logical organization aligned with the use-cases of archive users have been developed. Three levels of databases have been identified for this first prototype that involve both relational (MySQL) for the storage part and non-relational (mongoDB) for the logging part. The full system will serve as a complete testbed for the forthcoming ASTRI mini array archive system that will represent the seed of the CTA observatory.

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REFERENCES

[1] https://www.mpi-hd.mpg.de/hfm/HESS/.

[2] https://magic.mpp.mpg.de/.

[3] http://veritas.sao.arizona.edu.

[4] Actis, M. et al., "Design concepts for the cherenkov telescope array cta: an advanced facility for ground-based high-energy gamma-ray astronomy," *Experimental Astronomy* **32**, 193 (2011).

[5] Pareschi, G. et al., "The ASTRI prototype and mini-array: telescopes precursors for the Cherenkov Telescope Array (CTA)," *these proceedings* (2016).

[6] Lombardi, S. et al., "Astri sst-2m prototype and mini-array data reconstruction and scientific analysis software in the framework of the cherenkov telescope array," *these proceedings* (2016).

[7] Vercellone, S., "The ASTRI mini-array within the future Cherenkov Telescope Array," in [*Proceedings of the 5th Roma International Conference on Astro-Particle physics (RICAP 14)*], (2015).

[8] Pence, W. D., Chiappetti, L., Page, C. G., Shaw, R. A., and Stobie, E., "Definition of the Flexible Image Transport System (FITS), version 3.0," *Astronomy and Astrophysics* **524**, 42 (Dec. 2010).

[9] http://heasarc.gsfc.nasa.gov/fitsio/fitsio.html.

[10] http://www.mongodb.com.

[11] http://www.couchbase.com.

[12] http://info.couchbase.com/Benchmark_MongoDB_VS_CouchbaseServer_W.html.html.

[13] Schwarz, J. et al., "The alma software architecture," *SPIE* **5496**, 190 (2004).

[14] http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/caldb_intro.html.