PROCEEDINGS OF SCIENCE

Next-day observation processing for the LST-1 and MAGIC

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The MAGIC and LST-1 telescopes, located at the Roque de los Muchachos Observatory on La Palma, operate dedicated On-Site Analysis (OSA) pipelines that provide rapid, automated processing of observational data. These systems produce high-level data products just a few hours after observations are completed, enabling quick-look analyses, next-day data quality assessments, and rapid-response science such as flare detection and Target of Opportunity follow-ups. OSA pipelines have been in continuous operation since 2012 for MAGIC and since 2021 for LST-1, automatically processing nightly data using the standard analysis chain. The experience gained from both systems provides essential lessons for the development of Cherenkov Telescope Array Observatory's (CTAO's) on-site analysis, demonstrating the practical and scientific benefits of fast data processing in Cherenkov telescopes.

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1. Introduction

The first CTAO Large-Sized (LST-1) and the MAGIC telescopes are two Imaging Atmospheric Cherenkov Telescope (IACT) systems located at the Roque de los Muchachos Observatory on La Palma, Canary Islands, Spain. Figure 1 shows both instruments. Rapid availability of reliable analysis products to both collaborations is crucial for science alerts, scheduling, and data quality assurance. Additionally, the large size of the raw data makes its transmission to off-site data centres within a short time window challenging. On-Site Analysis (OSA) pipelines have been operational for MAGIC since 2012 and for the LST-1 since 2021. Both pipelines automatically analyse data using the standard analysis chain. These data serve as input for the daily checks performed on the data and the rapid analysis activities. In the case of MAGIC, an automatic analysis chain also derives the detection significance, spectra, light curves and sky maps of the observations. These last steps of the analysis are also currently being included into the LST-1 pipeline.

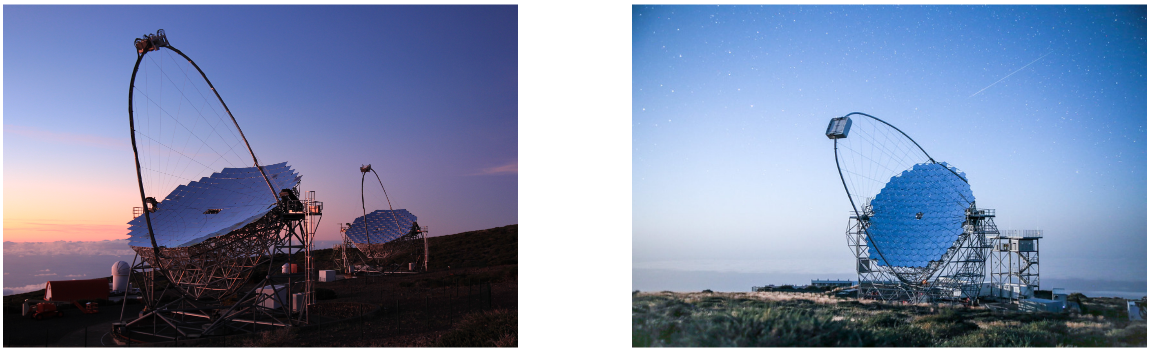


Figure 1: The MAGIC stereo system (left) [1] and the LST-1 telescope (right) [2], both located at the Observatorio del Roque de los Muchachos in La Palma. These imaging atmospheric Cherenkov telescopes are part of the current and next-generation facilities for very-high-energy gamma-ray astronomy.

2. Context

MAGIC is a two-telescope stereo system. With a trigger rate of $\sim$ 300 evts/s, the telescopes record up to 2 Terabytes (TB) of raw data per day [3]. The OSA pipeline processes data up to high-level products, such as sky maps and energy spectra. It operates on a dedicated system comprising approximately 50 cores and 40 TB of disk storage.

The LST-1 is a single telescope. With a trigger rate of $\sim 7-8$ kevts/s, it produces up to 30 TB of raw data per day [4]. Its OSA pipeline processes raw to reconstructed events (DL2, see Section 3), utilising an on-site data centre of 1,800 cores and more than 5 Petabytes (PB) of disk storage.

Both observatories rely on fast real-time analyses, which provide immediate estimations during the data taking at the expense of reduced sensitivity. They differ from the next-day analysis described here, which utilises the complete chain and provides high-quality data. Both approaches complement each other. Results from the next-day analysis are usually available before 14:00 local observatory time.

3. Structure of the systems

The data analysis of both observatories is similar. The telescopes are equipped with fast photomultiplier (PMTs) cameras with around 1000 (MAGIC) or 2000 (LST-1) pixels. When the Cherenkov light from an Extensive Air Shower, or a calibration pulse, arrives at the camera, the PMTs produce fast electronic pulses. After the trigger occurs, the pulse is digitised in a readout window, with 80 (MAGIC) or 40 (LST-1) samples per pixel. This data is recorded together with associated metadata and constitutes the lowest level data: Data Level 0 (DL0). After performing calibration, the reconstructed charge and arrival time per pixel are obtained (DL1). Images are then reconstructed, and the physical parameters of the original particle are estimated (DL2). Photon candidates are then selected in event lists, and the Instrument Response Functions are produced (DL3). This is the data that will be delivered to users in the future and serves as the basis for higher-level products. These steps are represented in Figure 2.

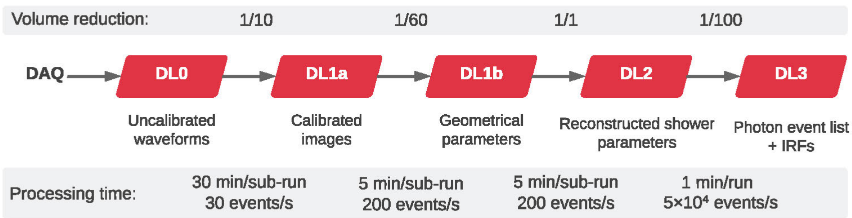


Figure 2: A simplified view of the LST-1 data flow, data size and processing time for each analysis step, it is very similar to the MAGIC one. Taken from reference [7].

The OSA system in the LST-1 is an evolution of the MAGIC OSA one; they are based on the same scheme, but the code has been almost completely rewritten. MAGIC OSA's pipeline is based on the Mars package [6] while the LST-1 OSA pipeline uses the lstchain software [5]. Several individuals have contributed to the work over the years (e.g., [7], [8], [9]). Both systems are primarily written in Python. Crontab jobs launch the main scripts, and the existence of key files controls their flow. In the pre-processing phase, information on observations is obtained from the DAQ databases and the slow control files, which contain the pointing information from the telescope. To initiate the analysis, a summary of the daily observations is compiled to guide the process, and the analysis jobs are subsequently launched based on it. Dependencies between different steps of the processing are taken into account when the jobs are prepared and during their execution.

During the first steps of the processing phase, which is the most time-consuming, the analysis is parallelised to the lowest possible level. Data is split into sets of files, equivalent to approximately 10 seconds of observation for LST-1 or 20 minutes for MAGIC. Individual jobs are launched for these units using a batch system (Torque for MAGIC and SLURM for LST-1). In the LST-1, several hundred cores are used in parallel, while in MAGIC the number of concurrent jobs is of the order of 10-20, albeit longer ones. During the processing, OSA interacts periodically with the system to check which jobs are finished and tag those with problems. The following steps are also run on the batch system but with a lower level of parallelisation.

LST-1 OSA integrates the production of data check summaries for the day and their transfer to websites where experts can later review them. In the case of MAGIC, the data check is performed by an independent system. In both cases, after the processing is finished, different processes merge the files, move them to their final locations and clean up the used directories.

After the processing is finished, a different system, independent of OSA, handles the transfer of data to the off-site data centres, where it becomes accessible to users. There, it is also available for rapid dedicated analysis, such as those conducted by flare advocates or triggered by "Targets of Opportunity".

A simplified scheme of the LST-1 OSA flow is represented in Figure 3.

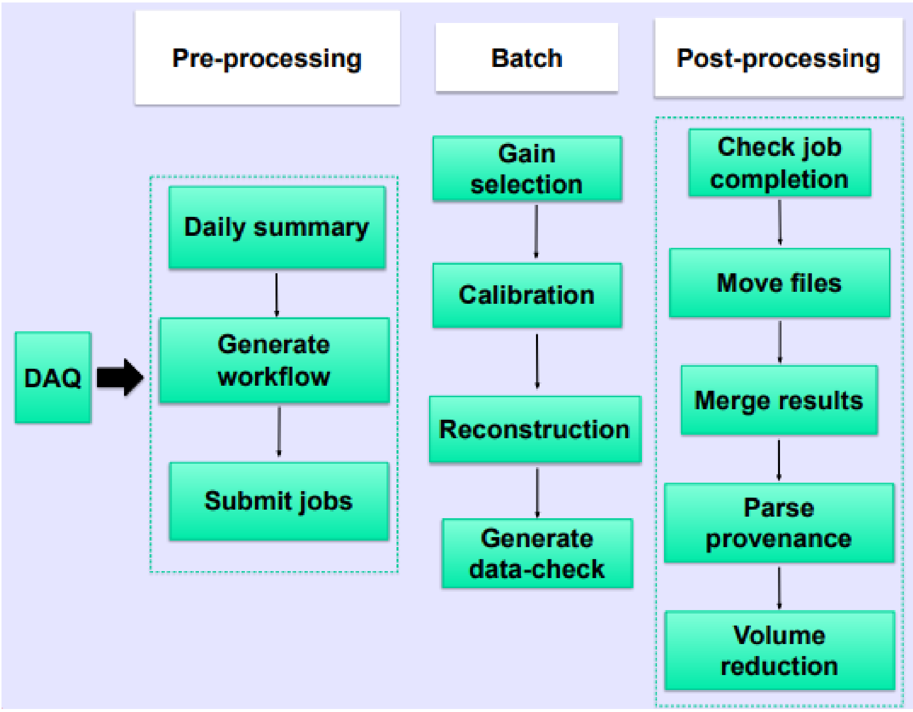
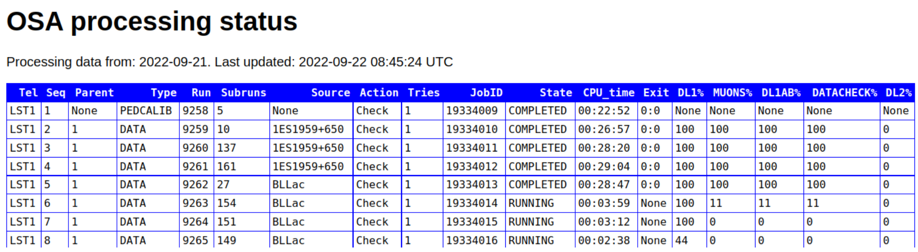


Figure 3: A simplified view of the LST-1 data flow, very similar to the MAGIC one.

OSA operates automatically, but several tools allow for the supervision of its functioning. Web pages, such as the one shown in Figure 4, display the status of the daily analysis. They are refreshed every few minutes while the analysis is running. Through them, the OSA teams and the whole collaboration can easily check the progress of the data reduction. Additionally, in the event of non-recoverable errors, the scripts notify the OSA teams via email.

To avoid both deadlocks and infinite loops, OSA incorporates an error-check system. When a process fails, it is relaunched a certain number of times, as its failure can be due to temporary conditions. After a few trials, the process is stopped and declared vetoed. Also, a limited amount of error recovery has been implemented to solve the most common issues. This information, including the number of trials for each job and any vetoing that may have been applied, is reflected in the above-described web pages. The OSA error recovery procedures are currently only available in MAGIC, but they are planned to be implemented for the LST-1 as well.



OSA processing status

Processing data from: 2022-09-21. Last updated: 2022-09-22 08:45:24 UTC

Tel	Seq	Parent	Type	Run	Subruns	Source	Action	Tries	JobID	State	CPU_time	Exit	DL1%	MUONS%	DL1AB%	DATACHECK%	DL2%
LST1	1	None	PEDCALIB	9258	5	None	Check	1	19334009	COMPLETED	00:22:52	0:0	None	None	None	None	None
LST1	2	1	DATA	9259	10	1ES1959+650	Check	1	19334010	COMPLETED	00:26:57	0:0	100	100	100	100	0
LST1	3	1	DATA	9260	137	1ES1959+650	Check	1	19334011	COMPLETED	00:28:20	0:0	100	100	100	100	0
LST1	4	1	DATA	9261	161	1ES1959+650	Check	1	19334012	COMPLETED	00:29:04	0:0	100	100	100	100	0
LST1	5	1	DATA	9262	27	BLLac	Check	1	19334013	COMPLETED	00:28:47	0:0	100	100	100	100	0
LST1	6	1	DATA	9263	154	BLLac	Check	1	19334014	RUNNING	00:03:59	None	100	11	11	11	0
LST1	7	1	DATA	9264	151	BLLac	Check	1	19334015	RUNNING	00:03:12	None	100	0	0	0	0
LST1	8	1	DATA	9265	149	BLLac	Check	1	19334016	RUNNING	00:02:38	None	44	0	0	0	0

Figure 4: Screenshot of one of the web pages that shows the LST-1 OSA data analysis status daily. The page is refreshed every ten minutes. Taken from reference [7]

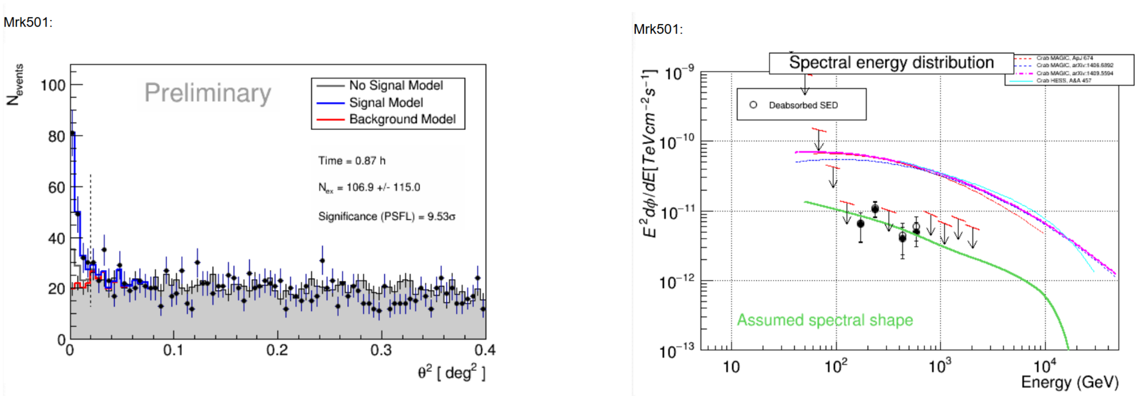


Figure 5: Examples of high-level plots produced by the MAGIC OSA pipeline from a recent observation of Mrk 501. **Left:** Classical θ^2 plot showing the significance of the source detection. **Right:** Spectral energy distribution (SED) corrected for extragalactic background light (EBL) absorption. These plots are generated automatically every day and are publicly available online for the collaboration members.

As previously commented, in the case of MAGIC, OSA processing extends beyond that of the LST-1, producing not only lists of photon candidates but also higher-level products, such as significance plots, sky maps, and spectra. Figure 5 shows a so-called θ^2 plot for a recent observation and a tentative SED (Spectral Energy Distribution). The first represents the histogram of events as a function of distance to the source, for both signal and background regions. Using these distributions, along with an estimate of the observatory's point spread function (PSF), the significance of a possible detection in an area close to the source position is estimated. The second plot contains a fast estimation of the source SED based on approximated instrument response functions.

4. Lessons learned

From the development and operation of the OSA systems over several years, we can extract several lessons that can be applied to similar observatories, in particular, the future CTAO ones.

As a first lesson, we are convinced that although disposing of a complete next-day analysis is a challenge, it is also a necessity for a Very-High-Energy (VHE) observatory. Firstly, it provides fast access to processed data, enabling a quick response to transient events. Additionally, it detects hardware and software problems that inevitably arise during telescope operation and facilitates the implementation of solutions within the analysis chain.

In the second place, it is clear that the next-day pipelines can not be isolated from the rest of the processing but should be tightly coordinated with the observatory databases and simulation tools.

As the third one, we note that although all tasks should be automatic, means for easy human intervention are always needed, and a comprehensive scheme for error detection and recovery should be established from the initial design.

These are only the main general points; several more detailed ones are detailed in references [7], [8] and [9].

5. Conclusions

On-Site Analyses have been working continuously for 13 years in MAGIC and 5 years in the LST-1 in the challenging environment of a mountain observatory.

Simple in design and effective, they have contributed to the success of both collaborations, providing fast, high-quality data, data check measures and, for MAGIC, quick basic physics results.

They can serve as a prototype, test bed and check for the future CTAO onsite pipelines.

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