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The LST-South as part of the CTA+ Program

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In the context of the Italian Resilience and Recovery Plan (PNRR), INAF and INFN proposed the "CTA+" Program aimed at extending the scope and strengthen the scientific return of the Southern Cherenkov Telescope Array Observatory (CTAO) site. The main objective of this program is to realize and implement two end-to-end Large-Sized Telescopes (LSTs) at CTAO-S as part of the LST Collaboration. The approved and full-funded program has formally began on January 1st, 2023 and has to be completed no later than December 31st, 2025. A similar procurement and implementation process is currently underway for CTAO's northern site, but some adjustments will need to be made to meet CTAO-S requirements. The baseline design of the mechanical structure will be based on that of the northern LSTs, apart from some possible changes to fulfil the environmental specifications of the southern site and further reduce the construction risks and costs. The mirrors will be produced using the same process as LST-N, a technology invented in Italy by INAF, via a cold replica of glass slabs to make the 2 m diameter mirrors. The camera will be almost identical to those of LST-N. The production of the cameras, mirrors and mechanical structures will be realized through large industrial contracts that will be supervised by the CTA+ management with the full support of the LST Collaboration.

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[*] Speaker

1. Introduction

The Cherenkov Telescope Array Observatory[1] (CTAO) is a European Research Infrastructure Consortium (ERIC) with headquarters in Italy, which will revolutionize the field of gamma-ray astrophysics thanks to its unprecedented sensitivity extending over 4 decades in energy (0.02-300 TeV). However, due to budget constraints, the approved CTAO "Alpha configuration" of the Southern Array in Chile does not yet include Large-Sized Telescopes (LSTs) and has a reduced number of Small-Sized Telescopes (SSTs). LSTs are needed to provide sensitivity below 100 GeV, which is key to probing cosmological and transient sources such as GRBs and multi-messenger targets from the most powerful explosions in the Universe. In the context of the Italian National Program for Recovery and Resilience (PNRR), INAF, in collaboration with INFN and several Italian Universities, has presented a project, nominally "CTA+", aimed at filling this gap by providing the much-needed additional telescopes, specifically two LSTs and five SSTs to be deployed in Chile. To maximize the scientific return, the program pursues the enhancements of INAF-led facilities (the VST and TNG telescopes, and the three Italian VLBI radio antennae) for electromagnetic multi-wavelength (IR/Opt/radio) follow-up observations, which would establish CTA+ as a cornerstone of the national multi-messenger strategy, in synergy with other PNRR multi-messengers proposals (gravitational waves with Einstein Telescope and neutrinos with KM3NeT). In addition, R&D activities will be done as "CTA spin-offs" including the Stellar Intensity Interferometry to be tested on the ASTRI Mini Array. Young scientists will be deeply involved in this program, and scientific education, outreach and communication will be carried out, in particular at the Headquarter in Bologna. "CTA+" aims to provide a unique opportunity to both the Italian and international communities to greatly enhance the scientific and technological returns associated with CTA. The "CTA+" program has been approved by the Italian Ministry of University and Research (MUR).

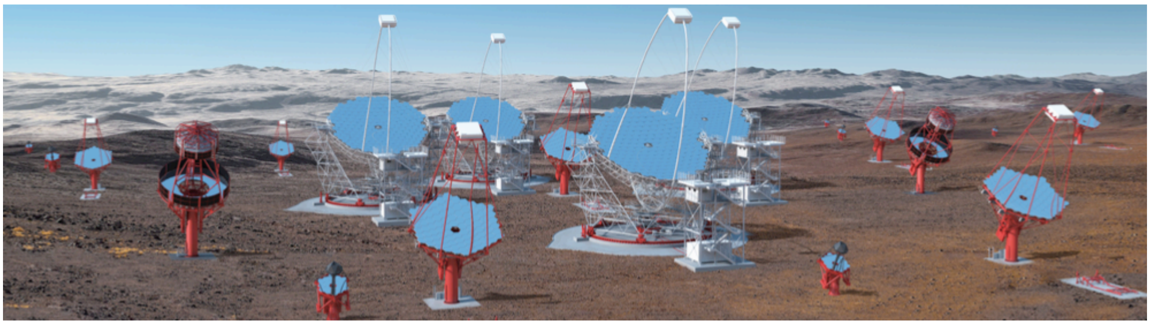

Figure 1: Rendering of CTA-South (credit: Gabriel Pérez Díaz, IAC / Marc-André Besel, CTAO)

2. Mechanical Structure

The LST is an alt-azimuth telescope that has a segmented mirror dish of 23m diameter and 28m focal length. The large reflection surface, with collection area of nearly 400 square meters, and high photo-detection efficiency allow it to detect low-energy atmospheric showers. These telescopes are deployed at the array's center (see Figure 1) to lower the energy threshold and dominate the

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[1] `https://www.cta-observatory.org/`

sensitivity of CTA between 20 and 150 GeV. The LST Mechanical Structure subsystem includes all the hardware and software allowing the telescope to point to different parts of the sky with the required performances. This subsystem includes all mechanical parts (structural elements, screws, bearings, gears, springs, and accessories) needed to support the telescope optics subsystem for collecting light. Moreover, the Mechanical Structure subsystem provides the motion capabilities that allow the Telescope to point and track over its specified range. All the electro-mechanical parts of the mechanical structure are provided with power and communication via dedicated supply lines. The already existing LST-North (LST-N) [1] is the baseline for the realization of these telescopes also in the south (LST-S). Nevertheless, because of more stringent anti-seismic requirements in the southern site, the LST-N structure can not be directly adopted for the LST-S. We are currently discussing some options, e.g., Option (a): employing the LST-N telescope structure with foundations including damping systems, Option (b): strengthening the mechanical structure, or other options between (a) and (b). The best solution for the realization of the LST-S mechanical structure will be decided in a bidding procedure.

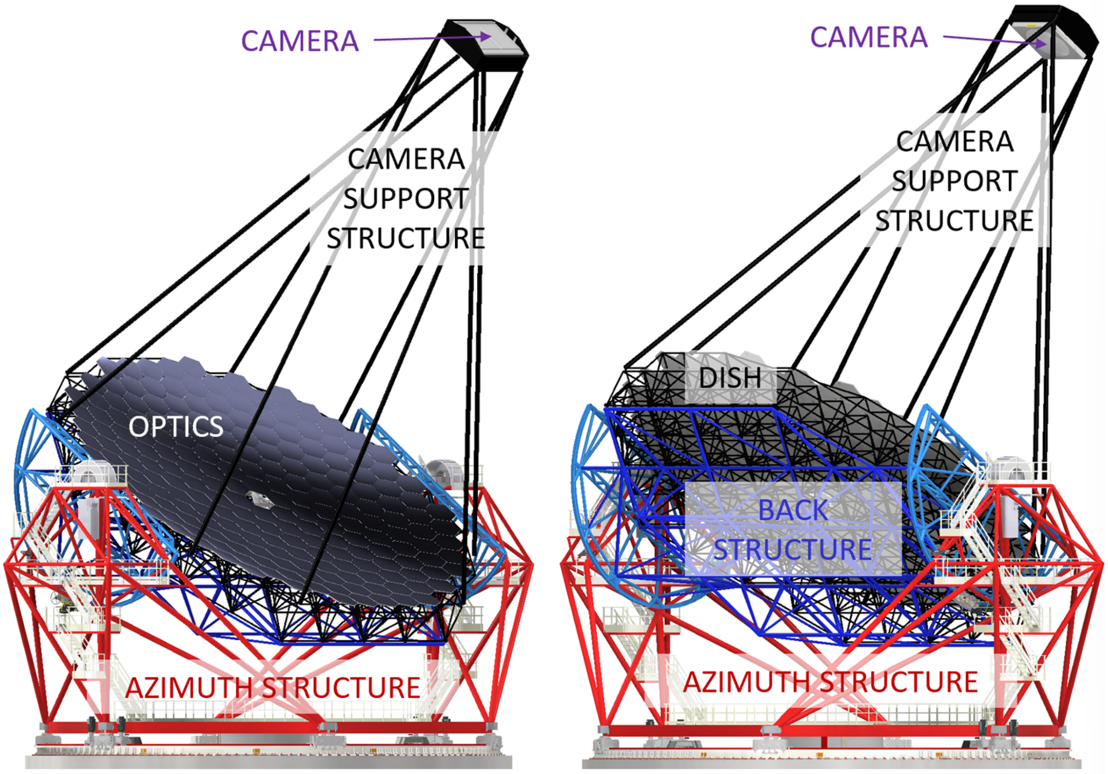

Figure 2: Rendering of the concept design for a LST at CTA-South (CTA-S) site.

We present a conceptual design of Option (b). This new design is made to adapt to different environments. In particular, this concept is developed to simplify the telescope structure and minimize the necessary elements (for example, we do not need the camera access tower). There is also the possibility that more potential manufacturing companies can build and assemble it because of removing the special elements. The adaptation focuses more on those details necessary to cope with different loads imposed by the environment (stronger earthquakes, less intense winds). The

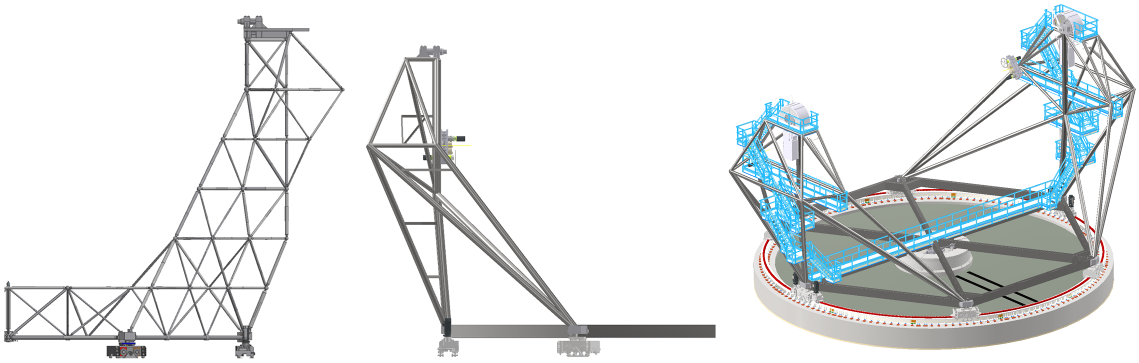

Figure 3: Comparison of azimuth structures (left: LST-N, centre: concept design for LST-S) and means of access (right)

azimuth structure is, in principle, very similar to the one used for LST-N but the lattice structure is replaced by a much lower number of beams to lower as much as possible the height of elevation axis with respect to the ground and provide more space for other auxiliary items like the access means. Consequently, reaching several parts of the telescope will become safer and quicker for the operators. The CSS (Camera Supporting Structure) consists of CFRP (Carbon Fiber Reinforced Plastic) straight crossed beams fixed to the dish, and there are no CFRP wires to support the CSS as in the case of LST-N. The dish structure is also made of the CFRP space frame, but the dish-supporting structure is made in steel. The elevation movement is realized thanks to a bridge and two lateral wheels replacing the back structure and the larger central wheel adopted in LST-N.

Figure 4: Comparison of elevation structures (left: LST-N, right: concept design for a LST-S structure))

As a result, the overall structure will be slightly heavier with 135tons versus 115tons (LST-N) due to the presence of more steel, but that will be suitable to get a stiffer structure with first eigenfrequency slightly above 2.1Hz in all elevation configurations and a very good behavior for the higher earthquake loads of southern site reducing accelerations at camera level. The dish and the bridge are structurally decoupled, since they are are made of different materials. The dish is fixed

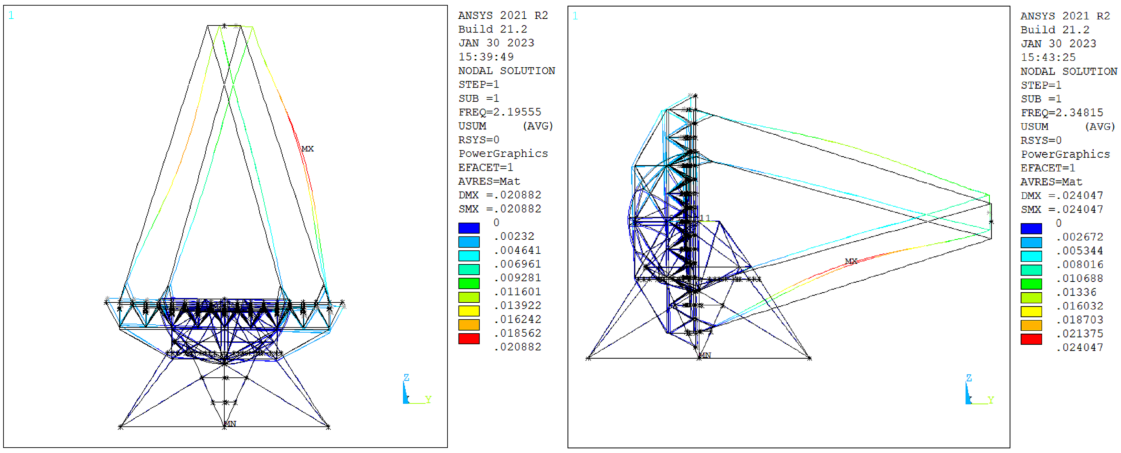

Figure 5: First natural frequency of the LST-S mount at zenith (left) and horizon (right)

firmly at the bridge center and it has further supports with the capability to allow radial expansion or contraction of the bridge induced by temperatures. Motion systems for LST-S, made by bearings, motors, and encoders, have a concept nearly identical to the one of LST-N for azimuth axis, while the elevation drive is different since there are two groups of motors, one per each wheel instead of only one. The choice to double the elevation motor groups has been done to have a higher redundancy but especially to have a better behavior of elevation structure motion with no (or much less) torsion between motors and encoders. Every motor group in azimuth and elevation includes two motors that work with a torque bias to avoid backlash phenomena. In azimuth the transmission is guaranteed by a traditional rim-gear concept, while for elevation there is a chain-sprocket concept; in this last case, the chain is fixed to the circumference of each of the lateral wheel. The straight camera support beams, different from the arch present in LST-N, allow to move the telescope in elevation to ground level (Figure 6). In this way, it is feasible to carry out maintenance for camera at ground level so the maintenance tower will be no longer necessary. Nevertheless, an interlocked pivoting system will be necessary to grant horizontal position for the camera during maintenance operations.

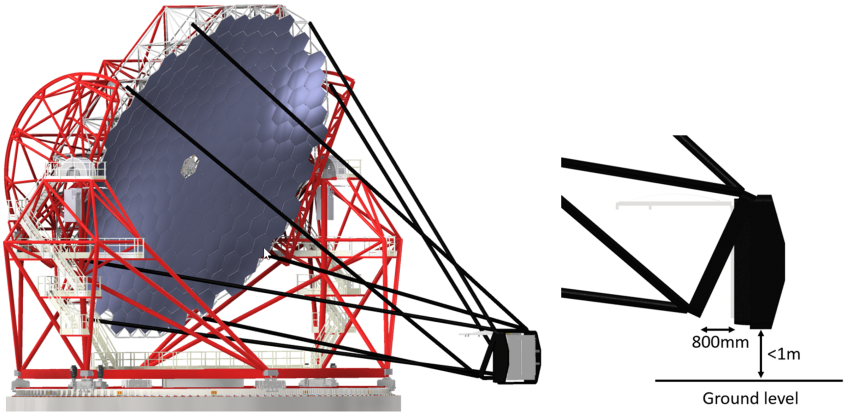

Figure 6: Telescope position during Camera maintenance

3. Mirrors

The LST-S segmented mirror dish comprised of 199 reflecting tiles that will create a monolithic 23m diameter parabolic optic with a focal length of 28m. Each panel's angular resolution (D80) requirement is about 2 arcmins. To achieve this, they will be produced via the cold glass replication method, which involves producing a series of spherical hexagonal segments (with a face-to-face distance of 1.5m, with varying radii of curvature) between 56m and 58m (see Figure 7 left panel). This method was invented in Italy and has been successfully used by INAF, in collaboration with Media Lario srl, to create mirrors for IACTs such as MAGIC I and II, ASTRI-Horn and ASTRI mini-array, MST/CTA, and pSCT [2–5]. In Japan, the University of Tokyo and the Sanko company also used a similar approach - with some differences - to produce the mirrors of the LST-N telescopes[6]. Figure 7 (right panel) illustrates the primary steps involved in mirror production. Firstly, a process known as "cold slumping" is utilized to bend a thin glass foil onto a mold with the desired profile. Next, an aluminum honeycomb layer is affixed onto the glass foil, followed by the addition of a second glass foil onto the honeycomb layer. As a result, a light yet rigid sandwich structure with an aluminum honeycomb core is created using the two glass foils. Once the glue has cured, the sandwich is released, and a highly reflective coating is applied to the outer surface of the inner glass foil. The coating will be applied via electron beam evaporation of an aluminum layer plus a protecting multilayer able to enhance the local reflectivity in the UV region up to 95% at 350nm.

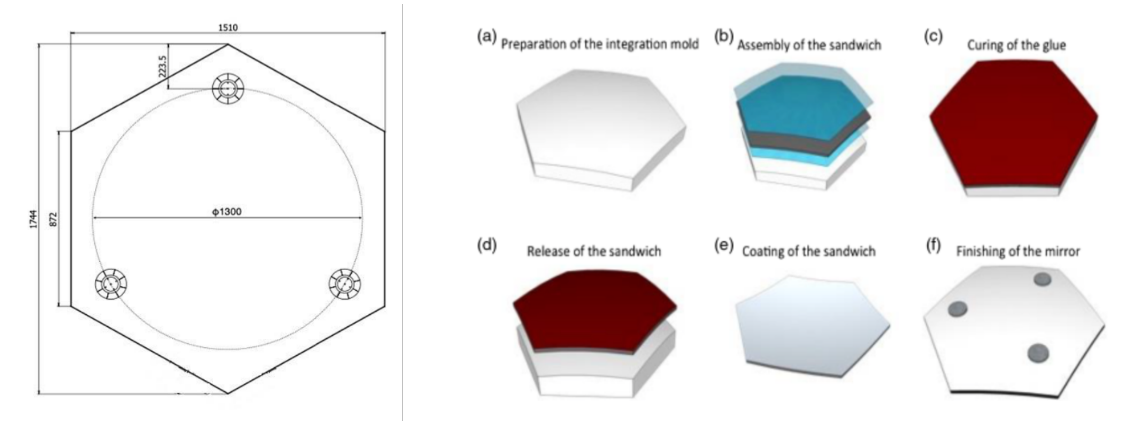

Figure 7: (left panel) Drawing of an LST-S reflecting panel, including the pads for interfacing the telescope structure. (right panel) Scheme of the cold replication process for the fabrication of a reflecting panel.

4. Cameras

The LST design is optimized for the lowest energies. The method to lower the energy threshold as much as possible is trigger single telescope deeply into the NSB (Night Sky Background) regime and wait for a trigger in another LST before reading out the event. The LST camera (LST-CAM) must sustain an acquisition rate of 10kHz and should assure a memory depth of at least 3500ns to operate in this mode and the required minimum photo-detection efficiency is 15%. The baseline solution for LST is to use classical photo-multiplier tubes with high quantum efficiency and low after-pulsing level. The selected light sensor for the first LST is the bialkali PMT R11920-100 from Hamamatsu Photonics (Figure 8 left panel), which has a spectral sensitivity optimized for the Cherenkov light spectrum [7]. The pre-amplification ASIC, dubbed PACTA (Pre-Amplifier for CTA), has a wide dynamic range (> 15 bit), a high bandwidth of 450MHz, a low power consumption (< 150mW), and low noise (4700 electrons for 10ns integration time)[8]. The low noise allows the discrimination of the single photo electrons. The core of the readout system is based on the DRS4 chip, developed at the PSI (Paul Scherrer Institute) in Switzerland Zurich and successfully used in MAGIC [9]. The memory depth of DRS4 chip can be enhanced to 4096 cells by cascading four channels. DRS4 chip perfectly embraces the LST-CAM concept, which implements a stereo trigger to achieve the lowest possible energy threshold and which requires a 4μs memory depth. The FPGA on the readout board configures and controls: the DRS4 chips, the discriminators in the trigger circuit, the Gigabit Ethernet transceiver physical layer (PHY), the analog-to-digital converters for digitizing the signal stored in the DRS4 chip sampling chip and the SRAM (Static Random Access Memory) that stores the digital data before transmission. In addition, the FPGA communicates with the programmable device (CPLD) of the Slow Control Board. The digitized waveform data and the monitor/control data are transmitted via Ethernet with only two devices, the FPGA and the PHY. The event as well as the monitor data are time-stamped in the FPGA by the internal clock. This clock is synchronized by one pulse-per-second and 10MHz clock signals supplied from the Level 1 trigger distribution board attached to the Readout Board.

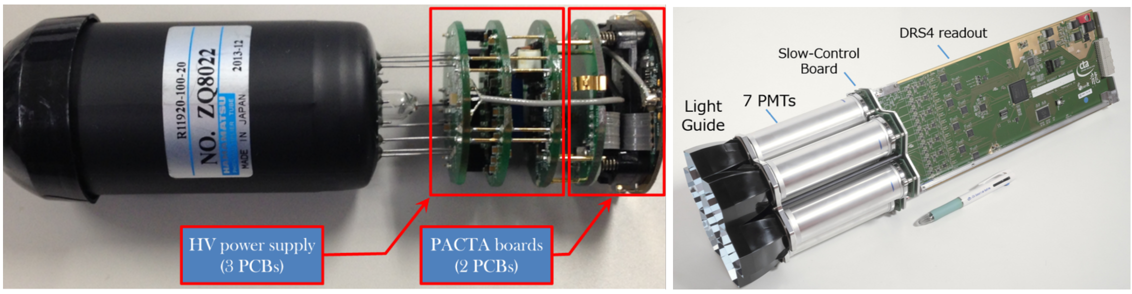

Figure 8: (left panel) The Photo Multiplier Tube with pre-amplifier. (right panel) The 7 PMTs module and the read-out electronics.

5. Auxiliaries

LST-South has an end-to-end approach, therefore it includes all the activities aimed at realizing an operating system including all the auxiliary systems for telescopes calibration. The LST-South telescope is a hardware/software system requiring an accurate and systematic calibration over a wide dynamic range by using a dedicated and specifically developed calibration systems: a Camera Calibration Box is necessary for calibrating LST cameras and illuminators are very important for periodic calibration of the single telescope as well as of the full array and we are realizing and installing these facilities. The LST Telescopes, both in northern and southern site, are remotely controlled by ACADA (Array Control and Data Acquisition) system developed under CTAO's supervision and interfaced with the Telescope Control System (TCS). The adopted control software for LST-S is the same developed for the northern array following requirement and specification discussed and approved by CTAO. A dedicated Information and Computing Technologies (ICT) infrastructure is also provided for operating the subsystems.

6. Conclusions

The larger and most ambitious goal of the CTA+ Program, led by INAF, is to realize two LSTs in the CTA south site in about three years by following an end-to-end approach. The two telescopes will be realized following the same baseline design of the northern LSTs, apart from those changes needed to fulfill the environmental specifications of the southern site and further reduce the construction risks and costs. The production of the auxiliaries, cameras, mirrors, and mechanical structures is realized through large industrial contracts supervised by the CTA+ management with the support of the LST Collaboration and CTAO. Some international partner countries in the LST Collaboration also provide in-kind contributions to the realization of part of the telescopes.

7. Acknowledgements

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