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The Spanish contribution to the CTA Observatory

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Abstract

The Cherenkov Telescope Array (CTA) project is an initiative to build the next generation ground- based Very High Energy gamma-ray instrument. It will serve as an open observatory to a wide astrophysics community and will provide a deep insight into the non-thermal high-energy universe. To achieve such goals, it will offer full-sky coverage (with Northern and Southern hemisphere sites), an improvement in sensitivity by about an order of magnitude, an enlarged span in energy (from a few tens of GeV to above 100 TeV), and enhanced angular and energy resolutions over existing VHE gamma-ray observatories. An international collaboration has formed with more than 1100 members from 28 countries all over the world. The Spanish High Energy Astrophysics community is deeply committed to CTA, with more than 70 scientists and technicians from 9 research groups currently involved in building prototypes for several CTA subsystems. This participation covers a wide list of items, both hardware- and software-related. The former includes telescope-level (camera electronics and mechanics and telescope undercarriage) and observatory- level (array optical calibration and atmospheric monitoring) elements. And the latter includes the design of the data pipelines and the scheduling for observational proposals. In this report, the status of the CTA project and the contribution of the Spanish community will be presented.

1 Introduction

Cherenkov telescopes have proven to be the most sensitive instruments of gamma-ray astronomy at Very High Energies (VHE), in the regime above 100 GeV. The Earth's atmosphere is not transparent to such high energetic photons, but it can be used instead as a detector medium, so that the cascade of secondary particles, which is produced when the cosmic gamma-ray strikes the atmosphere, can be measured by ground-based instruments. In particular, the secondary particles radiate blue Cherenkov light, which is recorded by means of large reflecting telescopes and enables the reconstruction of direction and energy of the primary gamma quantum.

The state of the art of research is represented by three existing infrastructures: HESS[1], in the Southern hemisphere, with four telescopes in operation since 2004, and a fifth one since 2012; MAGIC[2] with one telescope in operation since 2004 and a second telescope starting in 2009; and VERITAS[3] with four telescopes in operation since 2007, with both MAGIC and VERITAS located in the Northern hemisphere. More than 150 different sources of very high-energy gamma radiation have been discovered and characterised with these experiments.

The Cherenkov Telescope Array (CTA) is a global effort, with more than 1100 participating scientists and engineers from 28 countries, to deliver an observatory for astronomy with gamma rays of energies above 20 GeV. CTA will aim to:

- Provide full sky coverage,
- increase the sensitivity compared to current instruments by a factor ∼ 10 over a wide energy range from ∼ 20 to ∼ 300 TeV (Fig. 1 Right),
- improve angular resolution and Field-of-View (FoV) and hence the ability to characterize extended sources,
- enhance surveying capability, and allowing for simultaneous observations of multiple fields.

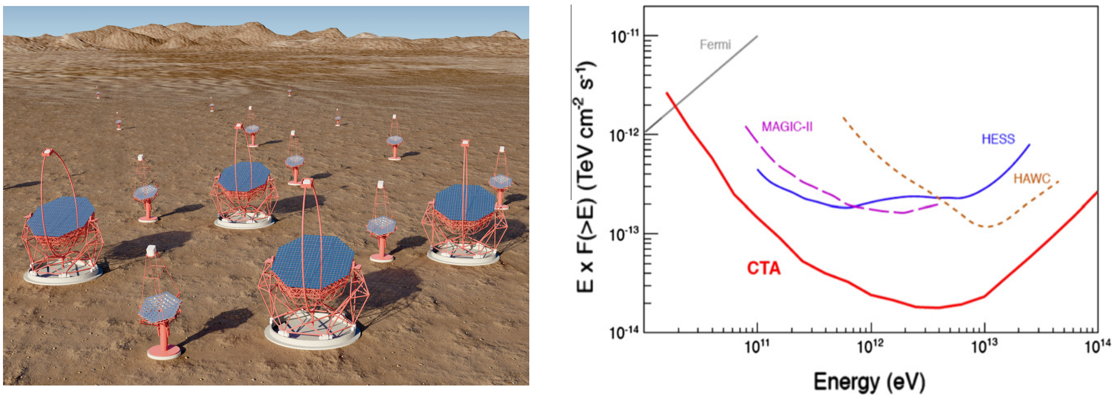

Figure 1: *Left*: The basic CTA concept. Artists view of the central part of a possible array configuration, including 4 LSTs, ∼ 30 MSTs, and ∼ 50 SSTs, at larger distances, scattered over several square kilometres. *Right*: Integral sensitivity for CTA from MC simulations, together with the sensitivities in comparable conditions (50 h for IACTs, 1 year for Fermi-LAT and HAWC) for some gamma-ray observatories [1].

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

[2] `http://wwwmagic.mpp.mpg.de`

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

To cover the entire gamma-ray sky a Southern and a Northern site are planned for the CTA observatory. Each site will combine imaging atmospheric Cherenkov telescopes of different sizes, about 100 in the South and 20 in the North (as sketched in Fig. 1; left), to cover a wide energy range. CTA will be an open, proposal-driven observatory, for the first time in VHE astronomy. A review of the status of the project can be found in [1, 6] and references therein.

The Spanish scientific community has been deeply involved in the CTA project since its beginning. Groups from CIEMAT, IAC, ICE-CSIC, IFAE, UAB, UB, UCM, UJ have formed a consortium (dubbed CTA-Spain) which participates in the design, prototyping and management of CTA in a coordinated way.

2 Scientific motivation

The aim of CTA is to make significant contributions in every aspect of gamma-ray astronomy, with special focus on the topics described below. All CTA-Spain groups have contributed to the definition of these topics.

Cosmic ray Physics. According to the most accepted scenario, galactic cosmic rays are accelerated in supernova remnants. During such acceleration and subsequent propagation processes, these cosmic rays interact with the surrounding interstellar medium, thus producing gamma rays. Therefore, CTA should be able to detect such population of gamma-ray-emitting SNRs, from which considerable insight into cosmic ray acceleration and propagation can be gained. Other galactic cosmic ray accelerators involving compact objects, such as pulsars, pulsar wind nebulae and gamma-ray binaries, will be also studied in this context. In addition, instruments of the current generation have shown that cosmic ray interactions with interstellar gas produce an observable gamma-ray flux from galaxies beyond our own. With CTA, the number of detectable galaxies should dramatically increase. This would allow the study of the connection between cosmic rays and star-formation processes in galaxies.

Black holes, jets and the star-forming history of the Universe. Supermassive black holes in the centres of active galaxies produce powerful outflows that offer excellent conditions for particle acceleration in shocks. CTA aims to measure large samples of such active galaxies of various types to study particle acceleration and gamma-ray emission processes. The observations of rather close-by radio galaxies can also shed light on the formation of the jet and its connection to the central black hole properties. In addition, Galaxy Clusters and Gamma Ray Bursts (GRB) will be studied in this context. Finally, the observations of some of the most powerful and most distant sources, the quasars, can tell us about the galaxy and the star-formation history of the Universe, which is imprinted in the amount and energy distribution of the extragalactic background light. On their way from a quasar to Earth the VHE gamma rays interact with this light and are absorbed. For a reliable estimate of the amount of this light, a large sample of spectra of Active Galactic Nuclei (AGN) needs to be measured, which CTA should provide with its largely increased sensitivity.

Fundamental Physics. A major open question in modern physics is the nature of dark matter. The most popular candidates are weakly interacting massive particles (WIMPs). The annihilation of such particles should produce detectable gamma-ray signals. CTA will have a much larger potential for dark matter detection than the current generation of IACTs. In addition, the improved energy coverage and resolution will make CTA an excellent experiment for other fundamental physics questions, such as searches for axion-like particles, effects of quantum gravity and other violations of Lorentz invariance.

3 CTA observatory

In order to achieve the above-mentioned performance, CTA will require three types of telescopes to cover a broader energy band, Large Size Telescopes (LSTs, 23 m diameter), Mid Size Telescopes (MSTs, 12 m), and Small Size Telescopes (SSTs, 4–6 m). Figure 2 (left) shows the baseline design for the LST. CTA-Spain participates in a wide variety of CTA activities. A description of the activities where the Spanish contribution is more important follows.

3.1 Large size telescopes

The purpose of LST is to enhance the sensitivity below $200 - 300$ GeV and to lower the effective threshold down to $20 - 30$ GeV. The science case of LSTs is the observation of high redshift AGNs up to $z \sim 3$, GRBs up to $z \sim 10$, and pulsars and galactic transients. LST will surely expand the VHE astronomy domain to cosmological distances and fainter sources with soft energy spectra. Additional details of the LST project can be found in [3].

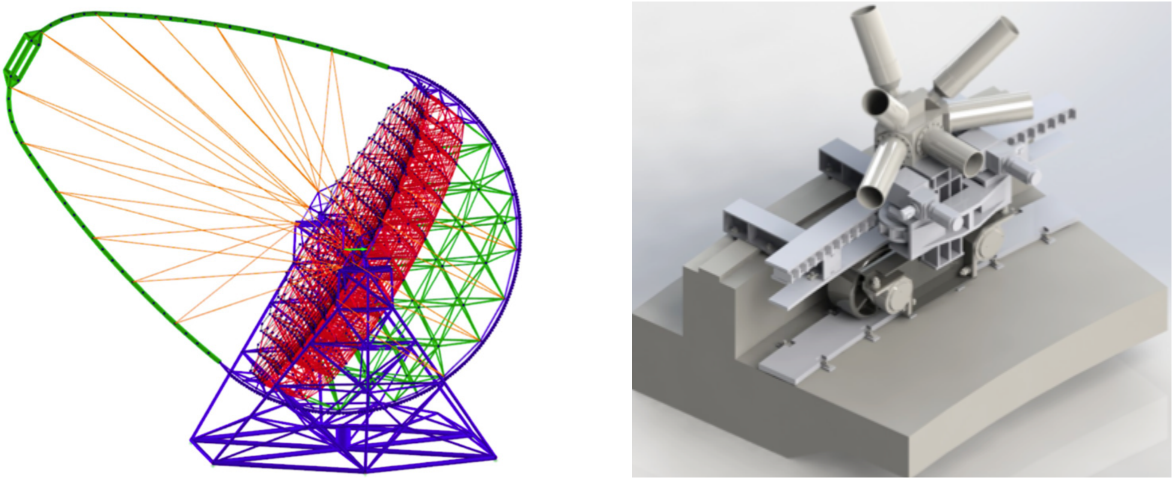

Figure 2: *Left*: the baseline design for an LST of 23 m diameter, with 4.5° FoV and 1880 pixels of 0.1° diameter. *Right*: design detail of the azimuth system.

LST structure and reflector system. The telescope geometry is optimized by Monte Carlo simulations and toy models in order to minimize the cost performance ratio. The baseline parameters are defined with the dish size of 23 m and the focal length of 28 m, leading then to f/d = 1.2. Figure 2 (left) shows the baseline design for the LST structure, which largely follows the MAGIC telescopes concept. It comprises several subsystems: the azimuth substructure and the mirror support dish, both based on space frame structures with carbon fiber reinforced plastic (CFRP) tubes; the camera support structure, relying on an arch formed by three curved sections for each of the arms, also using CFRP tubes, and 28 steel cables to stiffen the arch; and the azimuth and elevation systems, with their corresponding drive motors.

The azimuth system, which is responsibility of the CTA-Spain group at IFAE, will allow the telescope to turn around its vertical axis. The telescope structure rests on six bogies equally spaced in a hexagonal array. Each bogie has two wheels that turn in a double rail system, as shown in Fig. 2 (right). The two bogies withstanding most of the weight have two pinions powered by servomotors, turning the telescope. Bogies and rail are covered in order to extend the azimuth system lifespan.

The global reflecting surface of the LST must have a parabolic shape to keep the isochronicity of the optics. The entire reflector dish consists of 198 hexagonal mirrors with spherical shape, in a few sets of slightly different focal lengths. The dish overall parabolic shape will suffer deformations due to several causes. Therefore, an active mirror control system will be used to correct such deformations.

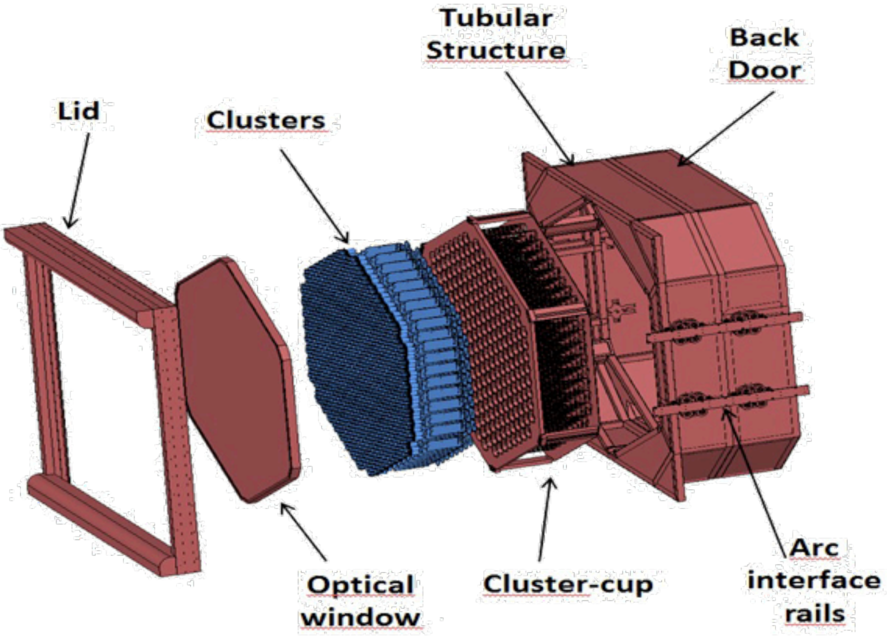

Figure 3: Camera mechanics design.

LST camera. Based on simualtion studies, the LST camera, placed at the focal plane of the reflector dish (see Fig. 2; left), will have a field of view of 4.5°. It can be divided in three different parts: the Focal Plane Instrumentation (FPI), the Readout Board (RB) electronics system and the global camera elements. All three parts go inside a sealed structure with temperature control.

The camera mechanics and cooling systems, which are responsibility of the CTA-Spain group at CIEMAT, are defined to fulfill the required working and environmental conditions inside the camera, and the positioning requirements of the camera pixels. The mechanics design (Fig. 3) allow the grouping of FPI and RB elements in 7-pixel clusters, while maintaining a strong constraint coming from the structure of the LST, which requires that the total camera weight does not exceed 2000 kg.

The FPI refers to the camera pixels and their ancillary electronics, and is based on PhotoMultiplier Tubes (PMT) with peak Quantum Efficiencies of 47%. The PMT signals are conditioned with custom-design preamplifiers dubbed PACTA (Fig. 4; top left) developed by a CTA-Spain group at UB, before reaching the RB electronics. PACTA is a wide dynamic range preamplifier with low power consumption and low noise.

The RB electronics system is based on analogue sampling memory chips DRS Version 4 (DRS4). The signal of each pixel, after it is conditioned in PACTA, is sampled at the DRS4

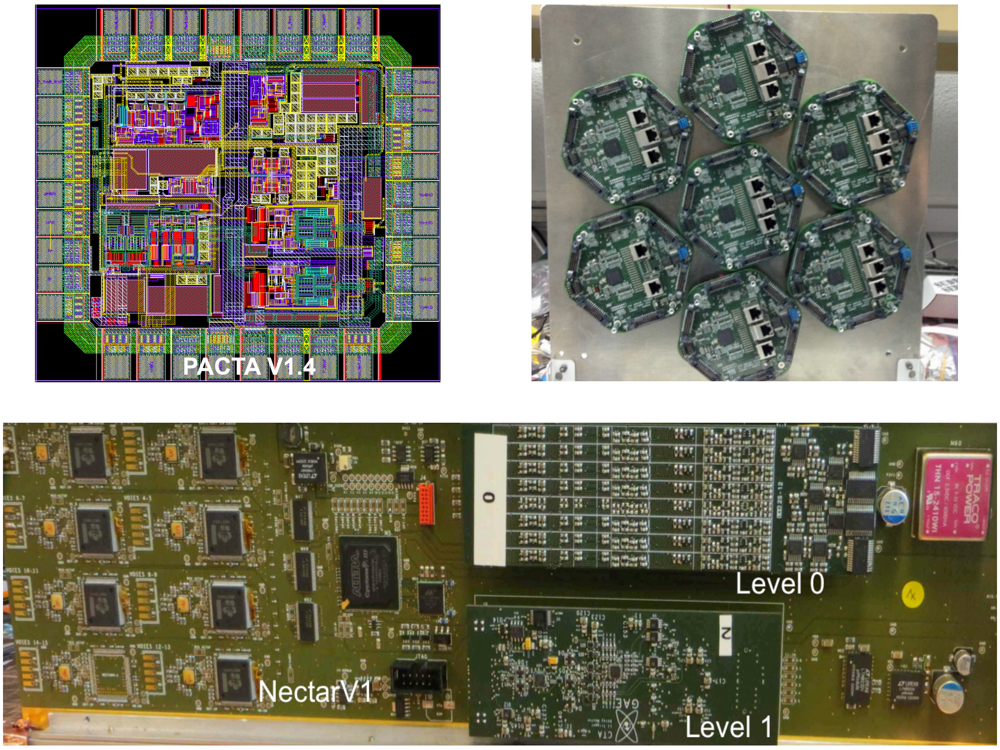

Figure 4: *Top left*: PACTA chip for the FPI system. *Top right*: prototype of the network of Backplane Boards. *Bottom*: trigger components on a MST cluster RB.

at a 1 GHz rate. When a trigger is generated, the analog signals from the DRS4 are digitized by an external slow sampling (30 MHz) ADC. The trigger system, which has been developed by CTA-Spain groups from CIEMAT, IFAE, UB and UCM, is producing this trigger signal by evaluating the analog signals from pixels, clusters and cameras of neighboring LSTs in a multi-level approach, and then distributing it throughout the camera RBs. The proposed solution for the LST camera trigger can be also adopted by the MST cameras. Figure 4 (bottom) shows some trigger components under test on a MST cluster RB, while in Fig. 4 (top right) a prototype of the network of Backplane Boards is presented, which will be used to distribute the trigger signal, along with additional servicing, to the RBs.

Finally, a group from UCM is taking care for the RAMS protocols of the LST project.

3.2 Observatory-wide developments

In order to obtain the required performance in a complex system like CTA, it is required to pay attention to many items regarding the whole observatory. CTA-Spain is taking a leading role in some of these items, such us the definition of the proper methods to calibrate the response of the telescopes and monitor the atmospheric conditions. For the former, a CTA-Spain group at UAB is leading the design of a Central Laser Facility [5] (CLF, sketched in Fig. 5; left) to inter-calibrate the optical properties of all CTA telescopes. For the later, groups at IFAE and UAB are participating in the construction of a Raman Lidar [4] (a prototype is shown in Fig. 5; right), which will allow to measure the atmospheric extinction due to aerosols and molecules.

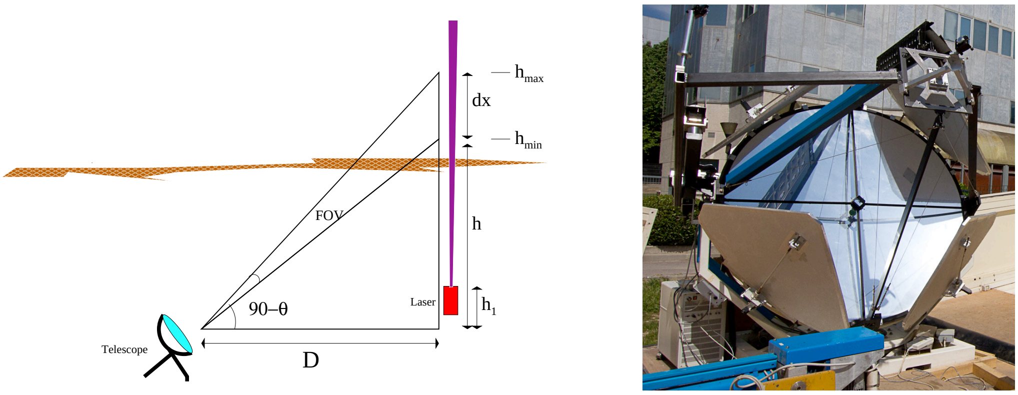

Figure 5: *Left*: sketch of a CLF principle of operation. *Right*: prototype of a Raman Lidar.

In addition, groups at IFAE and UCM have also participated since the initial stages of the CTA project in the Monte Carlo simulation required to optimize the telescope and observatory layout. Figure 6 shows one of the possible CTA layouts tested with Monte Carlo simulations, in search for the optimum array configuration, as well as the sensitivity for that layout. These simulations have also permitted the characterization of the different CTA candidate sites in terms of their expected scientific performances.

Finally, Spanish groups are also involved in the CTA control and operation. In this

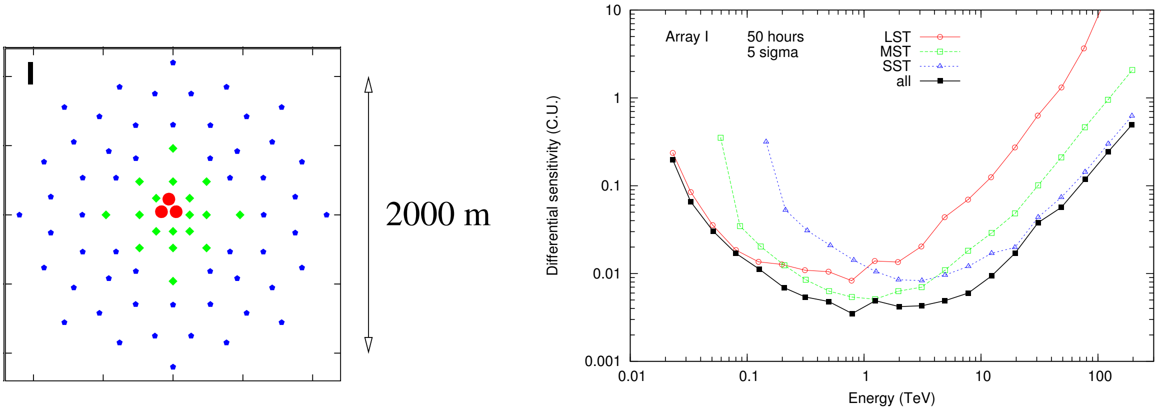

Figure 6: *Left*: one of the possible CTA layouts (dubbed array I) implemented in the Monte Carlo simulations. *Right*: sensitivity curves, in Crab Units, obtained from Monte Carlo simulations for array I, including the contribution for the different telescope sub-arrays, as detailed in [2].

respect, a group at ICE-CSIC is designing the scheduling system, which will permit the organization of the observations in a time-efficient way. Groups from IFAE and UCM are also leading the task to define the data model that will allow to establish the data reduction and dissemination schemes, in the scope of an open observatory and relying on the Virtual Observatory initiative. Figure 7 shows in a schematic way the CTA Observatory operation and its interplay with the scientific community, highlighting the CTA-Spain participation.

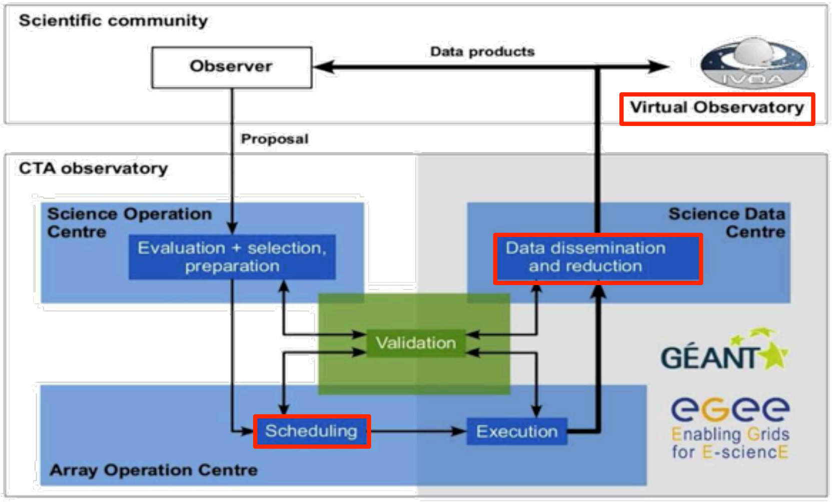

Figure 7: CTA Observatory control and operation scheme, with the activities contributed by CTA-Spain groups highlighted with red boxes.

4 Spanish candidacy for CTA Northern site

As already mentioned, the CTA Observatory will run two sites, one in each hemisphere. For the CTA Northern Site (dubbed CTA-North), Spain has proposed two candidate sites at the Observatorio Roque de los Muchachos (ORM) in La Palma island and the Observatorio del Teide (OT) in Tenerife island, both run by the IAC. The CTA Consortium has characterized all candidate sites, which have also been subjected to the evaluation of an external panel. Both reports are currently under the revision of the funding agencies that are supporting the CTA project, and will choose during the Spring of 2015 the final locations for both CTA-North and CTA-South.

Both the IAC and CTA-Spain are fully supporting the Spanish CTA-North candidates sites. In addition, the IAC and groups from IFAE, UAB and UCM, have contributed to characterize those sites as part of the CTA Consortium revision.

5 Conclusions and outlook

The CTA project has been developed during the last 8 years to build the largest ground-based gamma-ray open observatory, which will have one site in each hemisphere and will enhance the sensitivity of the current observatories by one order of magnitude. The international CTA Consortium has been set to design and construct this observatory. The project is currently in its prototyping phase, and during 2015 it will undergo both a Critical Design Review and the final selection of the Northern and Southern sites. Provided the review is passed, the pre-production phase will immediately start, so that by the end of 2019 the observatory should be fully operational.

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