Design Study of a CTA Large Size Telescope (LST)

MASAHIRO TESHIMA[1,2], OSCAR BLANCH[3], THOMAS SCHWEIZER[1], JUAN ABEL BARRIO[4], LAURENT BRUNETTI[5] EMILIANO CARMONA[6], PIERRE COLIN[1], JUAN CORTINA[3], FRANCESCO DAZZI[7], CARLOS DELGADO[6], GUILLAUME DELEGLISE[5], CARLOS DIAZ[6], DAVID FINK[1], NICOLAS GEFFROY[5] CHRISTOPHER JABLONSKI[1], HIDETOSHI KUBO[8], GIOVANNI LAMANNA[5], BRUNO LIEUNARD[5], ECKART LORENZ[1], GUSTAVO MARTINEZ[6], ABELARDO MORALEJO[3], REIKO ORITO[9], RICCARDO PAOLETTI[10], OLAF REIMANN[1], VICTOR STAMATESCU[3], HOLGER WETTESKIND[1], ON BEHALF OF THE CTA CONSORTIUM

[1]*Max-Planck-Institute for Physics, Munich, Germany*
[2]*Insisititute for Cosmic Ray Research, University of Tokyo, Chiba, Japan*
[3]*Institut de Fisica d'Altes Energies, Barcelona, Spain*
[4]*Universidad Compultense, Madrid, Spain*
[5] *Laboratoire d'Annecy-le-Vieux de Physique des Particules(LAPP), Universite' de Savoie, CNRS/IN2P3, Annecy,France*
[6]*Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas, Madrid, Spain*
[7]*Dipartimento di Fisica dell'Universit di Udine and INFN sez. di Trieste, Italy*
[8] *Department of Science, Kyoto University, Kyoto, Japan*
[9] *Socio-Arts and Sciences, The University of Tokushima, Tokushima, Japan*
[10] *INFN Pisa, Pisa, Itally*

masahiro.teshima@gmail.com

DOI: 10.7529/ICRC2011/V09/1021

Abstract: Following the great success of the current generation Imaging Atmospheric Cherenkov Telescopes, the preparation of the next generation VHE gamma ray observatory Cherenkov Telescope Array (CTA) is under way. It is designed to enhance the sensitivity to gamma ray sources, to enlarge the energy band and to improve the quality of data, i.e. angular and energy resolutions, and the gamma-hadron separation (low background and systematics). A few Large Size Telescopes (LSTs) of 23m diameter will be arranged at the centre of the array to lower the threshold energy and to improve the sensitivity of CTA below 200-300 GeV. The low threshold energy provided by the LSTs will be critical for CTA studies of pulsars, and high-redshift AGNs and GRBs. The status of the design study and prototyping of elements on CTA-LST will be presented.

Keywords: Gamma Ray, VHE Gamma Ray, Instruments

1 CTA Large Size Telescope

During the past few years, Very High Energy (VHE) gamma ray astronomy has made spectacular progress and has established itself as a vital branch of astrophysics. To advance this field even further, we propose the Cherenkov Telescope Array (CTA), the next generation VHE gamma ray observatory, in the framework of a worldwide, international collaboration. CTA is the ultimate VHE gamma ray observatory, whose sensitivity and broad energy coverage will attain an order of magnitude improvement above those of current Imaging Atmospheric Cherenkov Telescopes (IACTs). By observing the highest energy photons known, CTA will clarify many aspects of the extreme Universe, including the origin of the highest energy cosmic rays in our Galaxy and beyond, the physics of energetic particle generation in neutron stars and black holes, as well as the star formation history of the Universe. CTA will also address critical issues in fundamental physics, such as the identity of dark matter particles and the nature of quantum gravity.

CTA consists of three types of telescopes to cover a broader energy band, Large Size Telescopes (LSTs) of 23m diameters, Mid Size Telescopes of 12m meters, and Small Size Telescopes of 4-6m meters. The purpose of LST is to enhance the sensitivity below 200-300GeV and to lower the effective threshold down to 20-30GeV. The science case of LST is the observation of high redshift AGNs up to $z \leq 3$, GRBs up to $z \leq 10$, and pulsars and galactic transients. LST surely expands the domain of science to the cosmological distances and fainter sources with soft energy spectra.

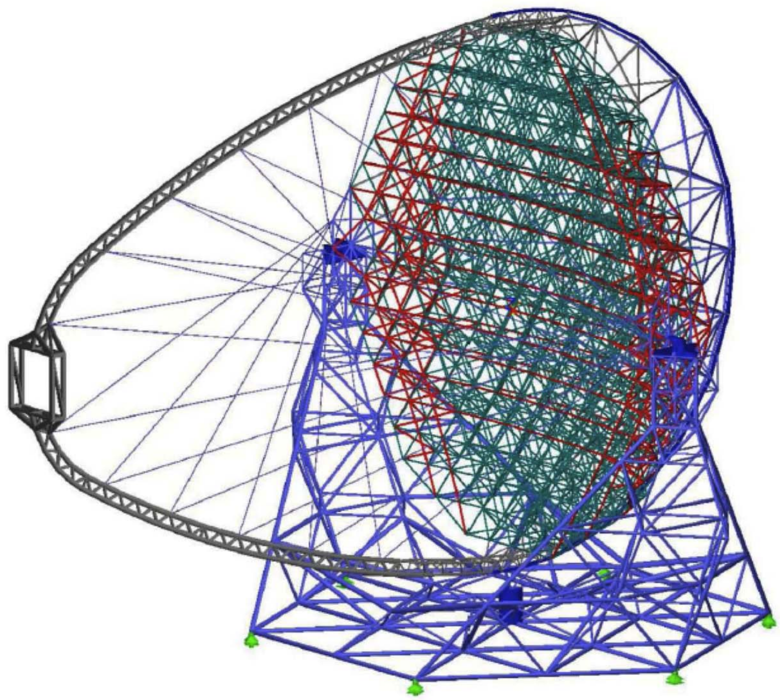

Figure 1: The telescope structure of LST designed by the MPI Munich group and MERO-TSK. The dish diameter is 23m and the total mirror area is about 400m^2. The focal length is 28m and F/D =1.2.

2 The Structure of the Large Size Telescope

2.1 Structure

The structure of the large size telescope (LST) as shown in figure 1 was designed by the MPI Munich group together with MERO-TSK. The major part of the telescope consists of the space frame structure with carbon fiber reinforced plastic (CFRP) tubes. The total weight of the telescope is designed to be about 50 tons and allows the fast rotation of the telescope, 180 degrees in 20 seconds, for the fast follow-up observations of gamma ray bursts using the location determined by gamma ray satellites.

The telescope geometry is optimized to maximize the cost performance by Monte Carlo simulations and toy models. The baseline parameters are defined with the dish size of 23m, the focal length of 28m and then F/D = 1.2, and the camera FoV of 4.5 degrees with a pixel size of 0.1 degrees.

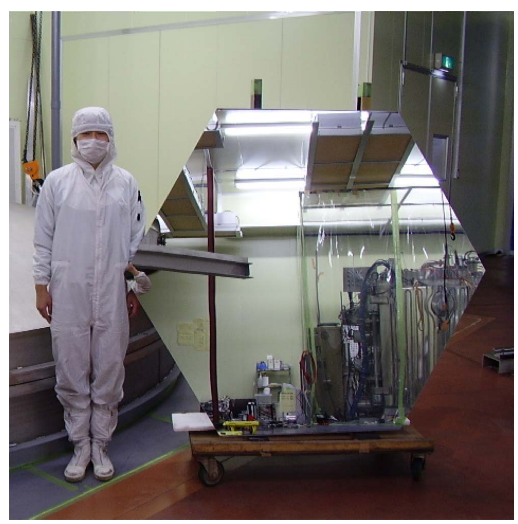

Figure 2: The prototype mirror of 1.5m flat to flat produced by CTA-Japan and the Company Sanko. The mirror with the sandwich structure of glass sheet of 2.7mm thickness - aluminum honeycomb of 60mm thickness - glass sheet of 2.7mm is produced with the cold slumping technique. The radius of curvature is about 56m. The weight is about 45kg.

2.2 Mirrors

The reflector with its diameter of 23m diameter consists of 198 units of hexagonal shape 1.5m flat to flat segmented mirrors of 2m^2. Total area of the reflector is about 400m^2. The individual segmented mirror is attached to the knots of the space frame structure with an universal joint, and two actuators. The segmented mirrors have a sandwitch

Figure 3: The 1/20 scaled telescope arch model for testing the arch oscillation damping by the LAPP group.

structure consisting of glass sheet of 2.7mm thickness - aluminum honeycomb of 60mm thickness - glass sheet. The weight of a segmented mirror is 45kg. The reflective layer of the mirror is coated with Cr and Al on the surface of the glass sheet with a protective multi-coat layer of SiO_2, HfO_2 and SiO_2. By adjusting the thickness of individual layers with SiO_2 and HfO_2, we can optimize the reflectivity to 95% due to the interference effect of multi-layers.

2.3 Active Mirror Control

We will define the optical axis (OA) of the LST optics with two infra-red lazers at the center of the dish constantly shining two targets left and right of the imaging camera. The individual segmented mirror will also have an infra-red laser at the edge of the mirror (MIR) which makes the spot at the target near the imaging camera confirm the direction of the mirror facet relative to the OA laser (optical axis). The directional offset of the mirror facets will be estimated by taking pictures of the MIR-laser and OA-laser spots on the target near the Camera with a high resolution IR CCD camera viewing from the center of the dish. If any significant offsets are found, the direction of the corresponding mirror facets will be corrected by actuators. The mirror directional calibrations over 198 mirrors will be done sequentially and performed within one minute. This calibration and control will be done continuously during the observation. After the first rotation for the GRB follow-up observation, or at the beginning of the observation of any source, we will use the look-up table corresponding to the zenith angle of the target source as the initial values of actuators and then move to the mode of permanent/continuous active mirror control loop.

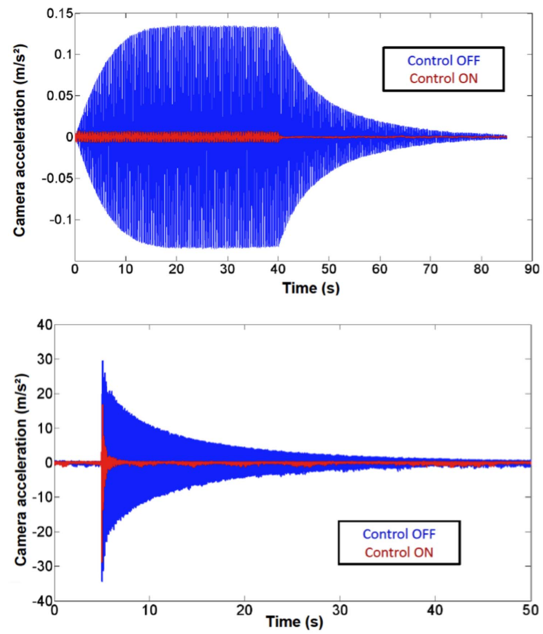

Figure 4: Measurements of the oscillations of the arch model with (Control On) and without (Control OFF) activation of the damping system. The significant improvements in the oscilation damping can be seen in sinusoidal and hammer-shock perturbations.

2.4 Arch Oscillation Damping System

The long structure of the arch (camera supporting mast), designed with CFRP tubes by the LAPP group will introduce non-negligible oscillations of the imaging camera under strong wind or after fast movement of the telescope. Such oscillations will be a source of temporal mispointings and also introduce mechnical instabilities in the long term. We will introduce the oscillation damping system, which actively changes the tension of the wires connecting the arch structure and two edges of the mirror supporting structure near the elevation axis. A demonstration of the oscillation damping system with a 1/20 scaled model was carried out by the LAPP group as shown in figure 4. It shows how the oscillation is suppressed / damped as a function of time with and without the damping system. We can observe the significant improvement in the oscillation damping in case of sinusoidal perturbation, like under a strong gust of wind, and also in case of hammer-shock perturbation, which may correspond to the fast rotation of the telescope.

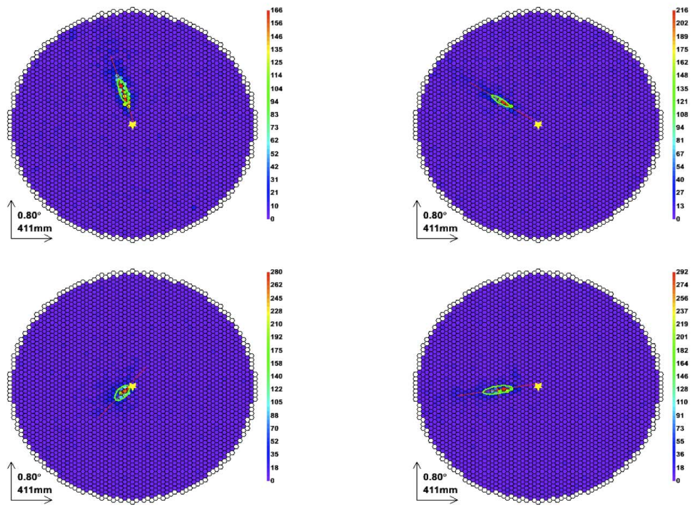

Figure 5: The typical image of the cherekov light images for a 50GeV gamma ray.

2.5 Imaging Camera

The imaging camera has a FOV of 4.5 degrees and a pixel size of 0.1 degrees. The actual size of the image plane will be about 2.2m in diameter. The signals from the photomultipliers will be read with 1G samples/sec speed and be stored in the ring capacitors of 4096 depth, which corresponds to 4 micro-seconds.

The camera should be sealed to resist the humidity and dust in the field. The front side (entrance window) of the imaging camera will be covered with uv-transparent plexiglass. Two water cooling plates are used to keep the temperature of the camera and the electronics constant. As a part of camera mechanical structure they will also serve as a support of PMT/electronics clusters. support. The readout electronics and the auxiliary electronics (HV, and amplifiers) will dissipate a heat of 2W/ch. 7-PMTs and readout electronics are mechanically bundled as a PMT/electronics cluster. The total number of pixels and clusters will become about 2000-2500 and 300-350, respectively. The total heat dissipation inside the camera will amount to 4-5kW.

2.6 The Sensitivity and Telescope Parameters

In order to optimize the cost performance of the LST array system, studies with toy models and Monte Carlo simulations are performed. We have assumed the following cost model: costs of the camera and the structure are proportional to the number of pixels, and to (mirror area)$^{1.35}$, respectively. We can formulate the sensitivity of the LST array system with parameters of the number of telescopes, diameter of the telescope dish, and FOV of the Camera using Monte Carlo simulations. Then with a fixed amount of budget, we can see the sensitivity of the LST array system as a function of the number of telescopes, FOV of camera,

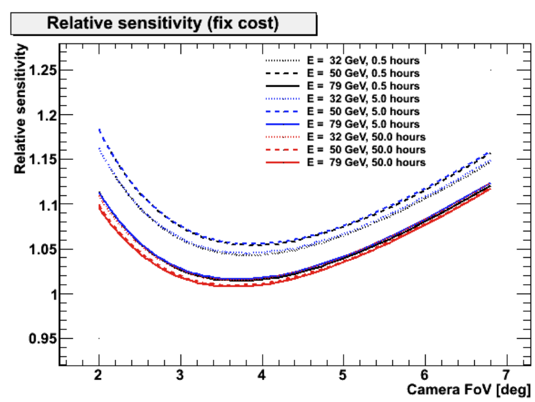

Figure 6: The sensitivity as a function of FOV with a constant budget. If we increase the FOV of the imaging camera, the cost of the camera will increase and the total number of telescopes will decrease and lose performance.

and telescope diameter. Figure 6 shows the sensitivity as a function of FOV for point source. The FOV of 4 degrees will give us the best sensitivity, be understood increasing the number of telescopes is more effective than increasing the FOV with a fixed budget. For extended sources of 1 degrees the best sensitivity is achieved with a FOV of about 4.5 degrees. The baseline design of the LST array system can be defined as the array of four LSTs with a dish diameter of 23m, FOV of 4.5 degrees.

Acknowledgement We gratefully acknowledge financial support from the agencies and organisations listed in this page: http://www.cta-observatory.org/?q=node/22