Nuclear Instruments and Methods in Physics Research A 806 (2016) 61–69

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

A facility to evaluate the focusing performance of mirrors for Cherenkov Telescopes

Rodolfo Canestrari [a,*], Enrico Giro [b], Giacomo Bonnoli [a], Giancarlo Farisato [b], Luigi Lessio [b], Gabriele Rodeghiero [b], Rossella Spiga [b], Giorgio Toso [c], Giovanni Pareschi [a]

[a] INAF-Osservatorio Astronomico di Brera, via Emilio Bianchi 46, 23807 Merate, Italy
[b] INAF-Osservatorio Astronomico di Padova, vicolo Osservatorio 5, 35100 Padova, Italy
[c] INAF-IASF di Milano, via Bassini , Milano, Italy

ARTICLE INFO

Article history:
Received 18 April 2015
Received in revised form
22 September 2015
Accepted 26 September 2015
Available online 9 October 2015

Keywords:
Cherenkov Telescopes
Mirrors
Scattering
Focusing

ABSTRACT

Cherenkov Telescopes are equipped with optical dishes of large diameter – in general based on segmented mirrors – with typical angular resolution of a few arc-minutes. To evaluate the mirror's quality specific metrological systems are required that possibly take into account the environmental conditions in which typically these telescopes operate (in open air without dome protection). For this purpose a new facility for the characterization of mirrors has been developed at the labs of the Osservatorio Astronomico di Brera of the Italian National Institute of Astrophysics. The facility allows the precise measurement of the radius of curvature and the distribution of the concentred light in terms of focused and scattered components and it works in open air. In this paper we describe the facility and report some examples of its measuring capabilities.

1. Introduction

1.1. Scientific framework

With the advent of the Imaging Atmospheric Cherenkov Technique (IACT) in late 1980s, ground-based observations of Very High-Energy gamma rays came into reality. Since the detection of the Crab Nebula using the IACT in 1989 by Whipple [1] the number of high energy gamma-ray sources has rapidly grown. Today the sources are more than 150 [2] and the number is increasing year by year thanks to the new generation experiments.

This first detection at TeV energies was followed by the discovery of the TeV emission from the first extragalactic source (Mrk 421), showing that acceleration processes are taking part in AGNs too [3]. With the present generation experiments like H.E.S.S. [4], VERITAS [5] and MAGIC [6] new classes of sources as well as about a dozen of unknown new ones were detected at GeV–TeV energies both galactic and extragalactic. The recent advances in γ-ray astronomy have shown that the 10 GeV–100 TeV energy band is crucial to investigate the physics in extreme conditions. Some interesting scientific topics are the Galactic Center, Pulsar Wind Nebulae, Pulsars and Binary Systems, Blazars, radio-galaxies, star-forming galaxies. For the interested reader, a comprehensive review on TeV Astronomy has been recently published in [7].

Ground-based experiments using Cherenkov photons produced in air represent a cost-effective way to implement observations in this band. At present, MAGIC, H.E.S.S. and VERITAS are the state of the art of such ground-based experiments. They have collecting area, obtained by combining several mirror segments, of the order of 500–1000 m^2.

The Cherenkov Telescope Array (CTA) represents the future generation of IACT, with the goal of increasing sensitivity by a factor of 10 with respect to the present best installations and a total mirror collecting area of the array of the order of 10^4 m^2. The CTA observatory is a project designed by a worldwide consortium that will make use of well demonstrated technologies of present generation Cherenkov Telescopes as well as new developed solutions. CTA will be based on telescopes with different sizes installed over a large area. At its southern site e.g. 70 Small Size Telescopes (4 m primary mirror diameter), 20 Medium Size Telescopes (12 m) and 4 Large Size Telescopes (23 m) are envisaged to be implemented in order to cover a broad spectral energy range from a few tens of GeV up to more than 100 TeV [8].

1.2. Mirrors calibration for IACTs

The mirrors for Cherenkov Telescopes are in general composed by many reflecting segments to be assembled together in order to mimic the full size mirror. So far, just single reflection telescopes have been used with Davis–Cotton or parabolic layouts. In both cases the segments are in general designed with a spherical geometry and proper radius of curvature. These mirrors are also

* Corresponding author.
E-mail address: rodolfo.canestrari@brera.inaf.it (R. Canestrari).

http://dx.doi.org/10.1016/j.nima.2015.09.092
0168-9002/

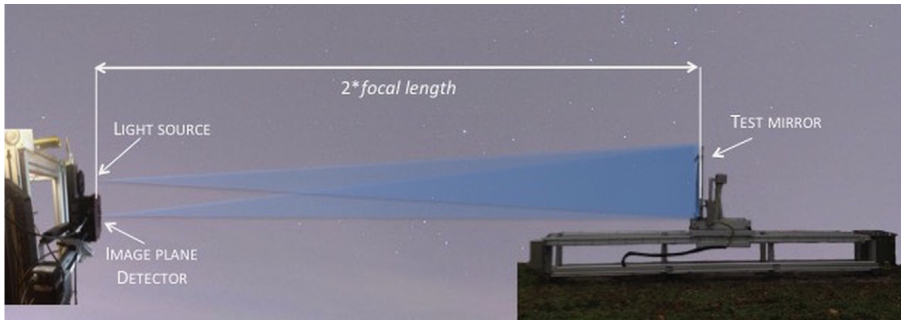

Fig. 1. Schematic representation of the 2-*f* method measurement setup.

characterized by a reflectivity performance typically above 80% (in the 300–550 nm energy band) but, at the same time, require angular resolution of typically a few arc-minutes, i.e. about two orders of magnitude the one of mirrors for optical astronomy. Despite the quite modest requirement in angular resolution, the distribution of the concentrated light is an important parameter in the performance of such telescopes. In fact, it has a direct impact on the measured energy and flux of gamma rays from the observed sources; and moreover in the determination of the energy threshold of the instrument [9]. Most of the current and future Cherenkov Telescopes make use of spherical mirrors; each telescope has hundreds of segments or even thousands in the CTA case [10]. In addition, it is common to have different suppliers for the same telescope. Production and testing of such mirrors need a full characterization through appropriate facilities with suitable set-up for the testing of the prototypes and to perform the quality control during the production phase in order to cross-calibrate mirrors from different industrial pipelines.

Optical properties, reflecting surfaces and mechanical structure are designed aiming at obtaining the best compromise between costs and performance. Cost of the industrial production has to be sufficiently low but it has to guarantee the requirements for Cherenkov optics. To address these issues, for instance, the CTA observatory is planning to take advantage of calibration facilities. Some of those are based on the direct imaging of a light source. There are already calibration facilities based on this method available in Tübingen (Germany) [11], Saclay (France) [12] and San Antonio de los Cobres (Argentina) [13]. Another approach which is now widely being used for mirrors, either Cherenkov or not, is based on the deflectometry method. It consists in observing the distortions of a defined pattern after its reflection by the examined surface and from them to reconstructing the surface shape. A facility based on this concept has been developed at Erlangen-Nürnberg University [14]. A variant of this method has been implemented at the Osservatorio Astronomico di Brera of the Italian National Institute of Astrophysics (INAF-OAB) to test and characterize the mirrors for the ASTRI SST-2M telescope proposed for the CTA [15]. A similar approach was previously used also for the characterization of mirrors for ring imaging Cherenkov counters [16].

In this framework, a new optical facility has been implemented by INAF-OAB. It has been designed and developed to test spherical mirrors with long radius of curvature (several tens of meters). The facility is a system working in open-air, so that accurate evaluation of the main parameters can be achieved under different environmental conditions. Moreover this facility is able to accurately investigate the scattering effect by means of a high sensitivity large format CCD camera. Several light sources with different spectral emissions are also available. In principle, this facility can be used either during the prototyping phase or the production phase. However, considering the high number of segments required by Cherenkov Telescopes the most appropriate use of this facility is to cross-calibrate the characterization pipeline of the suppliers and to perform random checks in the production. In this paper we present the facility and discuss its measuring capabilities.

2. Apparatus description

The facility measures the focused light of the mirrors using a simple optical configuration. Since mirrors have a spherical surface profile, a spherical wavefront can be used to generate the focal spot from the radius of curvature. This setup is commonly referred as 2-f method; it is sketched in Fig. 1. To retrieve the focal length f of the mirror under test the well known formula for the conjugate points can be used:

$$\frac{1}{f}=\frac{1}{p}+\frac{1}{q} \quad (1)$$

where p is the distance of the object (e.g. a light source) from the mirror and q is the distance of its image from the mirror. Assuming spherical mirrors (i.e. the typical geometry of the mirror segments used by Cherenkov Telescopes), once the light source is positioned at a distance of $p = 2 \cdot f$, then the image can be seen at the same distance $q=p$, because the incoming rays hit the surface of the mirror perpendicularly and are reflected back along the incoming direction – this distance being the radius of curvature $r = 2 \cdot f$ of the mirror under test.

The above-mentioned optical setup is the simplest one to check the imaging quality of the mirrors, however it requires a long baseline. The only possibility to provide a setup with a shorter length would be to produce parallel light rays which hit the surface and get focused at a distance $q=f$ from the mirror (called 1-f method). The problem with the 1-f setup is that one needs a light source emitting parallel rays which illuminate the whole mirror facet (typically larger than 1 m^2), which would be much harder to realize.

The equipment needed to perform the 2-f test is schematically based on a light source, a detector and a room which shall be large enough to host the baseline. Our facility is indeed composed of two stages. The stage #1 is a mirror's support structure mounted on a long travel rail. The mirror's support and the rail are motorized in order to allow the alignment of the mirror under test. Fig. 2 shows a rendering of the design study performed on this part and a photo. The stage #2 is located into a control room where a compact bench hosting a light source and a detection unit take place. This system is motorized, thus enabling the possibility to scan the focusing plane. A control-command unit (i.e a desktop computer), an electrical cabinet and storage space complete the apparatus.

The facility is installed at the Merate (Lecco, Italy) site of INAF-OAB. It is based on a long baseline to fit mirrors with radii of curvature ranging from 30 m up to 36 m. This choice was driven by the fact that most of the current and future Cherenkov Telescopes (e.g. H.E.S.S., MAGIC and CTA) make use of mirrors with similar characteristics. Moreover, the stage #1 is installed outdoor, thus giving the possibility to study also the mirror performance for different thermal conditions, i.e. mimicking the real operative