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Optimization of the Light collector design of the 21m diameter MACE γ-ray telescope

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A generalized ray-tracing procedure has been developed and used for studying the optical properties of the 21m diameter (f/1 system) tessellated light collector of the MACE telescope, proposed to be set up at Hanle, India (32.8°N, 78.9°E, 4200m asl). The light collector will use 356 panels of size ∼984mm×984mm with each panel having 4 or 9 small spherical mirrors fixed on it. The results of the ray tracing simulation studies, carried out for several light collector designs, suggest that using a paraboloid basket along with mirror panels of graded focal lengths in the range 2109-2245 cm yield the best possible focusing and timing characteristics. The D_{95} values of this light collector design are determined to be ∼29.3mm (≡ 0.08°) and ∼84.7mm (≡ 0.23°) at incidence angles of 0° and 1°, respectively and are significantly smaller than those of the conventional paraboloid design using mirror panels of the same focal length. The Davies-Cotton design, on the other hand, although found to yield slightly better off-axis characteristics at incidence angles beyond 0.75° as compared to the graded focal length paraboloid design, introduces a time spread of ∼9 ns which can lead to a contamination of the genuine Cerenkov signal from unwanted light of night sky background.

1. Introduction

A typical atmospheric Cerenkov imaging telescope uses an optical reflector to collect the Cerenkov light associated with an extensive air shower, which develops as a result of a primary γ-ray (or cosmic-ray) propagating in the upper atmosphere. While the main purpose of using a large diameter light collector is to lower the threshold energy of the telescope, the light collector should also have the ability to focus the Cerenkov light flash onto a multi-pixel camera in a manner such that the intrinsic differences in the angular distributions of Cerenkov photons produced by γ and cosmic-ray initiated showers are faithfully reproduced to allow efficient discrimination between these two event species. Keeping in view the fact that it is extremely costly and difficult to construct a monolithic light collector with more than few meter diameter, even though the mirror surface quality requirement of a Cerenkov telescope is far less stringent than that of an optical telescope, almost all the presently operational atmospheric Cerenkov imaging telescopes use a tessellated light collector design. This involves putting together a large number of small-sized spherical mirrors on a basket in an appropriate geometrical arrangement so that their combined surfaces are equivalent to a single large mirror with a common focus.

2. Light-collector design of the 21m diameter MACE telescope

The 21m-diameter MACE (Major Atmospheric Cerenkov Experiment) telescope, proposed to be set up at Hanle, India (32.8 ° N, 78.9 ° E, 4200m asl) is an atmospheric Cerenkov imaging telescope to explore the γ-ray energy domain ∼ 20 GeV - 10 TeV. The imaging camera of the telescope will comprise a cluster of 832 PMTs of two sizes, providing a field of view of 4° ×4°. While the innermost 576 pixels, covering a field of view of 2.4° × 2.4°, will have a pixel resolution of 0.1° for generating the event trigger, the remaining 256 pixels will have a resolution of 0.2°. The light collector of the MACE telescope (f/1 system) will use 356 panels of size ∼ 984mm × 984 mm with each panel consisting of either 4 or 9 small spherical mirrors of size ∼488mm×488 mm and ∼323mm × 323mm, respectively. In order to simplify the installation and the alignment procedure, 4 (or 9) mirror facets will be grouped together so that the resulting mirror panel thus formed behaves like an equivalent single large spherical mirror of size ∼984mm×984 mm. This scheme of using a mirror panel as a single mechanical unit instead of individual mirror facets leads to two significant advantages. Apart from making the alignment and testing procedure common and simple for all panels which is independent of their position on the basket, the method also helps in reducing the cost of the other hardware components which are needed for providing active alignment control of the panels during actual observation runs.

With regard to the optimization of the MACE light collector design, although using a Davies-Cotton design has been found to be quite satisfactory for ∼12m class Cerenkov imaging telescopes [e.g HESS [1,2] and VERITAS [3]) because of its better off-axis focusing properties than that of the paraboloid design, choosing this design for the 21m-diameter light collector leads to a time spread of ∼ 9ns which can lead to an undesirable increase in the threshold energy of the telescope. It is for this reason only that the MAGIC group [4] has preferred to use the paraboloid light collector for their 17m diameter telescope. Furthermore, it has also been suggested by the MAGIC group [4] that the focusing properties of the conventional paraboloid design can be significantly improved if graded focal length mirror panels are used. The main aim of this paper is thus to investigate various possible light collector designs so that an optimum geometry can be found for the MACE telescope which apart from being isochronous also yields a point spread function comparable to that of the Davies-Cotton design. In order to facilitate such comparison we have divided the MACE light collector into 12 zones so that mirror panels of different focal lengths can be used in these zones for achieving the best possible point spread function. The details of the mathematical formulation used for conducting this study are discussed in [5]. Since the procedure described in this reference is valid only for circular-shaped mirrors, a minor modification in the rotation matrix (involving a third rotation) had to be incorporated so that the geometry of the square mirror panels is maintained in accordance with their actual layout.

Fig.1a shows the projection of the mirror panel layout onto a plane transverse to the symmetry axis of the light collector basket. The results of the graded focal length optimization for all the 12 zones are shown in Fig.1b, where optimized mirror panel focal lengths are plotted as a function of their average radial distance from the light collector axis. Although there is no logical reason for choosing two different zones at Zone-07 and Zone-08 with panels of same focal length, it has been done here only for convenience so that we can demarcate mirror panels with 4 facets (Zone-01 to Zone-07) and mirror panels with 9 facets (Zone-08 to Zone-12). The mirror panels with 9 facets have been shown as shaded squares in Fig.1a. The number of mirror panels to be used in each zone has also been indicated in Fig.1b.

It is pertinent to point out here that spherical mirror panels placed atop a large paraboloid basket can mimic a large paraboloid mirror only in a situation when the individual spherical mirror panels used are of arbitrarily small size. Since this condition is not strictly met in the present situation, it is unjustified to expect that the paraboloid design chosen here will yield optical characteristics akin to those of a single large paraboloid mirror. Furthermore, since the point spread function of an optical system can be evaluated analytically only in simple cases involving a single optical element, desirable information regarding the optical characteristics of a tessellated mirror configuration can be obtained only be using a detailed ray tracing procedure.

3. Comparative performance of various light collector designs –simulation results

For purposes of proper intercomparison, we have studied the following 4 light collector designs: Paraboloid light collector with graded focal length mirror panels (PGF); Paraboloid light collector with constant focal length mirror panels (PCF); Davies-Cotton (DC) and Single Monolithic Paraboloid light collector (PML).

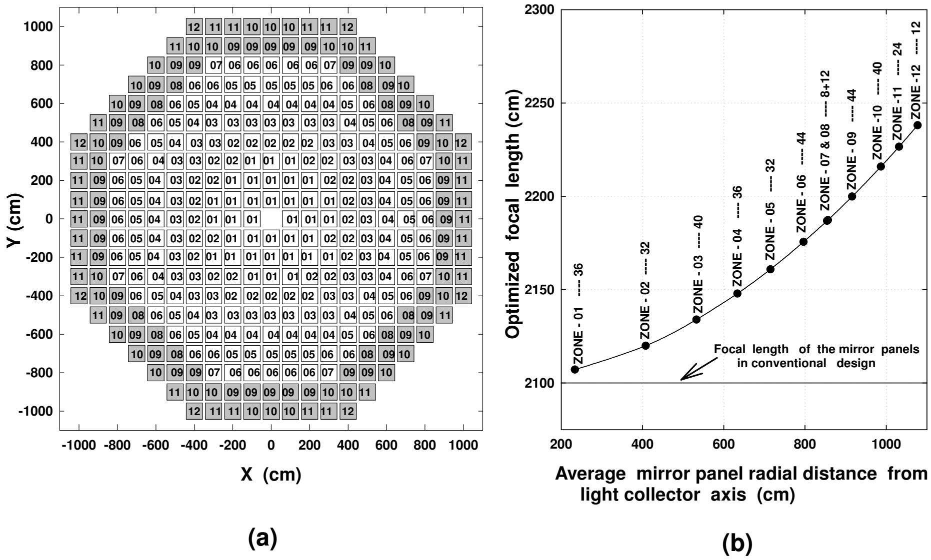

Figure 1. (a) Projection of the 356 mirror panels of the tessellated light collector of the MACE telescope. The division of the light collector into 12 zones are also labeled in the figure. (b) Variation of the optimized mirror panel focal lengths as a function of their average radial distance from the light collector axis.

While evaluating the performance of these light collector designs we have assumed the mirrors to be ideal surfaces. Several characteristics of the simulated images were studied including D_{50} (and D_{95}), which are defined as diameters of circles, concentric with the centroid of the image, within which 50% (and 95 %) of the reflected rays lie. Variation of D_{50} and D_{95} values as a function of the incidence angle is shown in Fig.2 for all the four designs. It is quite evident from Fig.2b that using a PGF design with mirror panels of graded focal lengths in the range 2109-2245 cm yields much better focusing properties than that of PCF design for all incidence angles. The D_{95} values of this light collector design, found out to be $\sim$ 29.3mm ($\equiv$0.08°) and $\sim$84.7mm ($\equiv$ 0.23°) at incidence angles of 0° and 1°, respectively, are significantly smaller than that of the PCF design. It is also seen in Fig.2b that the PGF design yields slightly better on-axis focusing characteristics than that of the DC design, because of the larger distance between the outer mirror panels from the focal point in the PGF design. This helps in reducing the astigmatism for these mirror panels, which is otherwise a dominant contributor to the overall aberration budget in the DC design. Likewise, the reason as to why the DC design yields better off-axis properties at incidence angles beyond 0.75°, is because of the reduction in the "global" coma in the DC design due to the overall shape of the light collector.

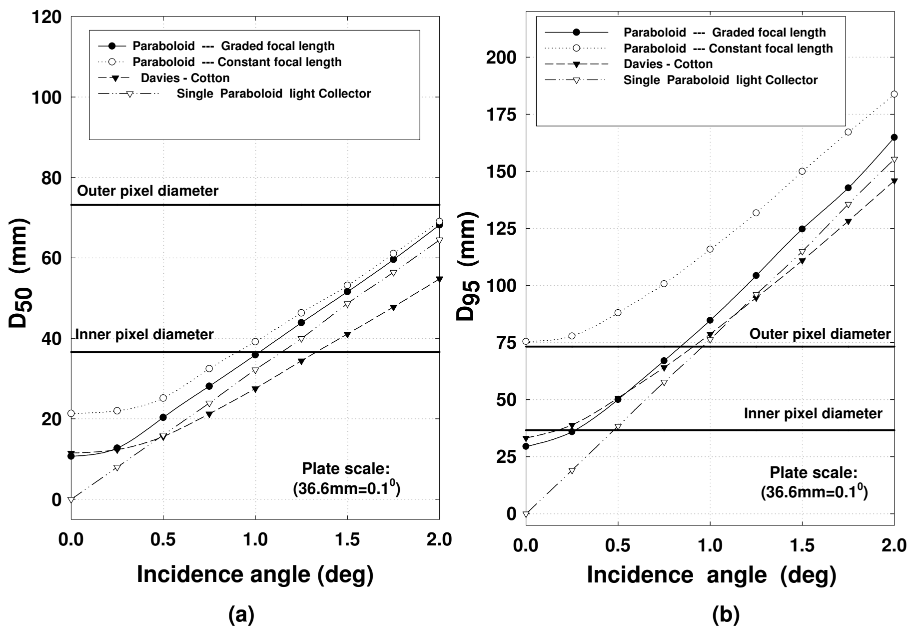

Figure 2. Variation of D_{50} (a) and D_{95} (b) as a function of angle of incidence.

4. Conclusions

The results regarding the optimization of the MACE light collector suggest that using a paraboloid basket along with mirror panels of graded focal lengths in the range 2109-2245 cm yields the best possible focusing and timing characteristics. While degradation of D_{95} as a function of manufacturing tolerances in the focal length values of the mirror facets has also been studied, indicating that 1% variation in the focal lengths of the individual mirror can be easily tolerated, the effect of the non-ideal behaviour of individual mirror facets is still under investigation.

References

[1] K.Bernlohr et al., Astropart. Phys., 20, 111 (2003).
[2] R.Cornils et al., Astropart. Phys., 20, 129 (2003).
[3] T.C.Weekes et al., Astropart. Phys., 17, 221 (2002).
[4] R.Mirzoyan et al., Nucl. Phys. (Proc. Suppl.) 54B, 350 (1997).
[5] A.K.Tickoo et al., Nucl. Instr. & Meth. A 539, 177 (2005).