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Salient mechanical and optical design features of 25m-diameter light-collector of MACE imaging Gamma-Ray Telescope

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Abstract. A low-threshold energy, high-sensitivity γ–ray telescope, MACE (for Major Atmospheric Cerenkov Experiment) is proposed to be built in India for explorations of γ–ray sky in 100's keV - 10's GeV photon energy range, hitherto inaccessible from ground. This paper outlines the scientific motivation for this major telescope system and focusses on its mechanical design aspects. Preliminary simulation results, obtained on the expected optical quality of the overall light collector, are also discussed.

Key words : galaxies : Gamma-Ray Telescope, Large Light collector, CFRP, EGRET sources

1. Introduction

In gamma-ray astronomy, the energy range between ~ 20-100 GeV is essentially inaccessible at present due to the limited effective geometrical factor (detector x area solid angle) of current satellite-based gamma-ray telesopes (e.g., EGRET) and the higher threshold energy (~ TeV) of the on-going ground-based experiments. There are, however, several persuasive reasons for studying this hitherto-unexplored window in a detailed manner (Bhat, 1997; Dingus, 1995; Barrio et al, 1998), the more prominent among them being: (i) Investigations of the spectral evolution of EGRET sources (including γ–ray pulsars and active galaxies) (ii) Understanding the nature of the unidentified EGRET objects (both galactic and extra galactic) (iii) Learning about galaxy-evolution in the early epochs of the universe and (iv) Searching for high-energy spectral tails in the cosmic gamma bursts (Hurley et al, 1994)

In view of the strong physics motivation referred to above, we are planning to build the imaging gamma-ray telescope, MACE, as a major component of the GRACE gamma-ray astronomy facility (Bhat, 1997) being set up presently at Mt. Abu, Rajasthan.

2. MACE mechanical design

The MACE (Bhat, et al, 1999) proposes to deploy a 25m-diameter, quasi-paraboloid, graded focal-length light-collector which is placed on an alt-azimuth mount and is provided with 2-axes steerability. Its focal-plane instrumentation will consist of a high-definition photo-multiplier tube (PMT)-based Cerenkov imaging camera (FoV ~ 6^0, pixel number=600, pixel-resolution ~ $0.15^0 - 0.25^0$). This instrument would allow to carry out high-sensitivity γ–ray investigations in the above-referred energy bracket (MACE mode of operation). A piggy-back focal-plane instrumentation, again made up of 480 PMT detectors, arranged in a circular ring of 10m diameter around the MACE imaging camera, will enable to carry out ground-based detection and localization of cosmic γ–ray bursts through the atmospheric scintillation technique (BEST-mode of operation).

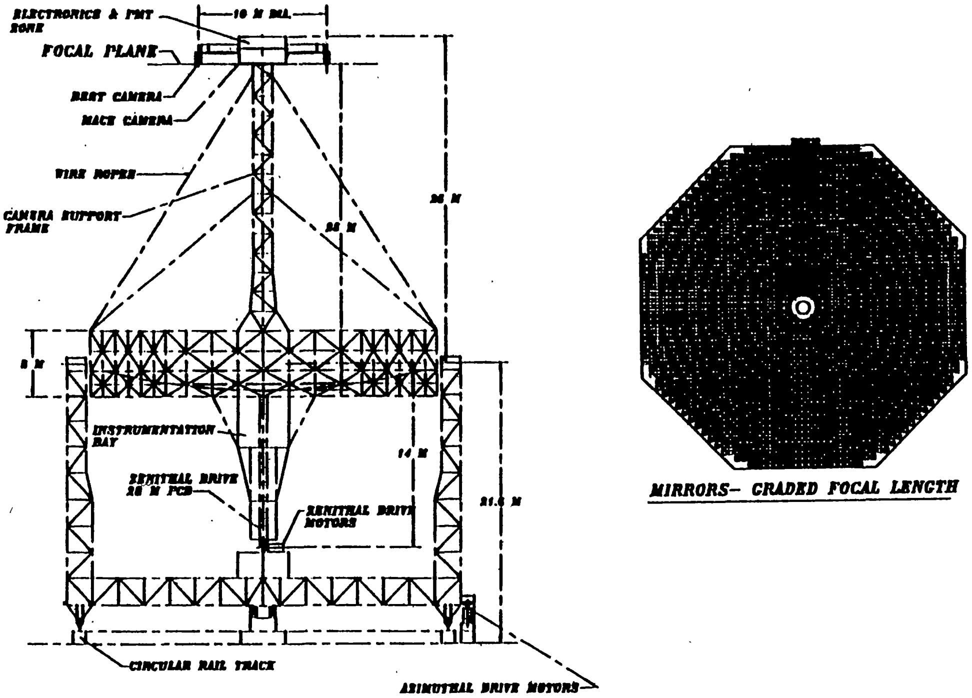

Figure 1. The details of the mechanical structure and the layout of the mirror facets of the MACE.

Keeping in mind the weight, weathering and fabrication-cum-assembly considerations, we are planning to use Carbon Fibre Reinforced Plastics (CFRP) for the tubular frame structure of the MACE. The mirror facets are proposed to be made up of high-reflectivity, diamond-turned aluminium sheets which are backed up with Al honeycombs for the desired structural rigidity. As indicated in Fig.1, the basic mechanical elements of the MACE are (i) a concrete foundation with a circular rail for azimuthal movement (ii) an azimuthal under-carriage with drive motors for azimuthal rotation (iii) a tubular space frame (iv) tessellated reflector (v) an altitude drive ring and a drive motor (vi) a camera support frame and (vii) the focal-plane instrumentation (MACE and BEST cameras).

The important mechanical specifications of the telescope are (i) a graded focal-length quasi parabolic reflector, isochronous with ≤ 1 ns (ii) active light collection area ~ 97% of the total reflector area (iii) individual mirror surface accuracy ~ 0.2 microns (iv) source pointing time for telescope < 1 min. for any direction in the sky (v) tracking precision ≤ 1 arc min; and (vi) Safe operation in wind speeds upto 60 km/hr with survival wind speed of upto 150 km/hr.

Each mirror facet will use a 6 mm thick sheet of 6061-T6 Al alloy, machined on a CNC diamond turning machine, a sandwitch honey-comb layer 25mm in thickness and a 1 mm thick bottom plate of 3003 Al alloy. A set of individual mirror facets will be aligned and fixed on a structural panel made up of an aluminium honeycomb sandwitch which will in turn be fixed to the telescope space frame. Active position control of these panels is proposed for maintaining accurate alignment of the mirror-facets in all telescope positions.

Some of the presently on-going activities related to the MACE are : (i) deflection analysis of individual elements in the unit cell and structure of the space frame (ii) stress analysis of mirrors, structural panels and support structure (iii) machining of mirrors to optical quality and (iv) the realiability analysis. Vendors for the CFRP tubes required for the MACE structure are being identified.

3. Spot-size Simulation

Here the spot-size is defined as the (angular) diameter of the circle within which 90% photons, from an incident parallel beam, are received in the focal plane of the mirror after reflection from the light collector surface. For these 'first-feel' simulation results, the MACE light collector is regarded as comprising 2459 spherical mirror facets of size 0.49 x 0.49 m,

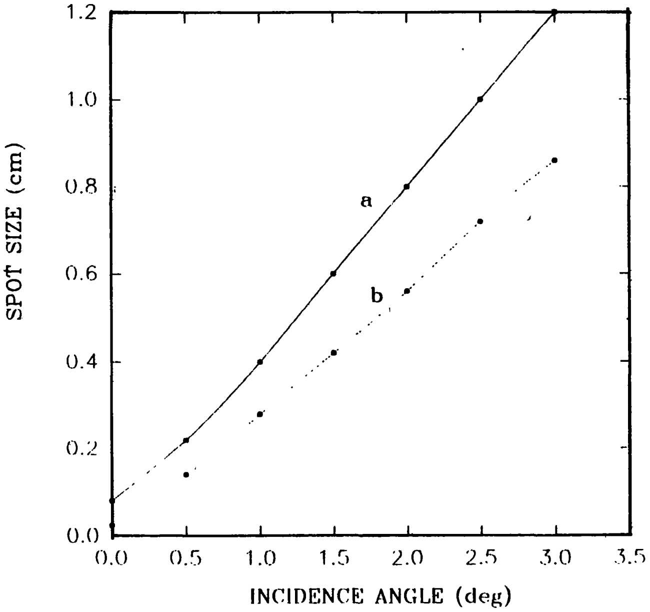

Figure 2. Variation of the spot size formed at the focal plane of the MACE as a function of incident angle for (a) fixed-and (b) graded focal length facets.

which are arranged on a quasi paraboloid surface in the form of concentric rings. No surface irregularities are considered in the mirror facet. Spot-size estimates have been carried out for two cases, where the individual mirror facets have (i) a constant focal length (25m) and (ii) graded focal lengths, gradually increasing from 25 m to 26.44 m as we go out from the light collector centre to the outermost ring (12th) of the light-collector rim. The results are shown in Fig.2 for both the cases as a function of the incidence angle, *l*. For the first case (fixed focal length), the linear spot-size is found to vary from 0.4-12mm for $l = 0\text{-}3^{\circ}$, while for the graded focal length case, the spot-size changes between ~ 0.24 - 8.4 mm over the same range of angle of incidence. It is evident that the graded focal length approach improves the spot-size by 30 - 70% compared with the fixed-focal-length case. As the basic structure in both the cases is a paraboloid surface, the advantage of isochronocity is retained by both of them.

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