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Salient mechanical design features of the proposed 17 meter diameter 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 focuses on its mechanical design aspects.

Key works : Galaxies, Gamma-Ray Telescope, Large Light Collector, EGRET sources.

1. Introduction

In Gamma-ray astronomy, the energy range between ~ 10-100 GeV is essentially inaccessible at present due to the limited effective geometrical factor (detector area x solid angle) of current satellite-based experiments. There are, however, several persuasive reasons for studying this hitherto-unexplored window in a detailed manner (Bhat, 1997; 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.

In view of the strong physics motivation referred to above, we are planning to build the 17 meter size imaging Gamma-ray telescope, MACE, as a major component of the GRACE Gamma-ray astronomy facility being set up presently at Mt. Abu, Rajasthan.

2. MACE Telescope mechanical design

2.1 Description : The MACE Telescope, (Fig. 1) proposes to deploy a 17 meter 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 "MACE" camera (FoV – 4 degree, pixel numbers = 832, pixel-resolution –0.1 degree – 0.2 degree). 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 112 nos. PMT detectors, ("BEST" Camera,) arranged in a square ring of 4 m x 4 m size, 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). Full details of the cameras are presented in a separate paper in this symposium.

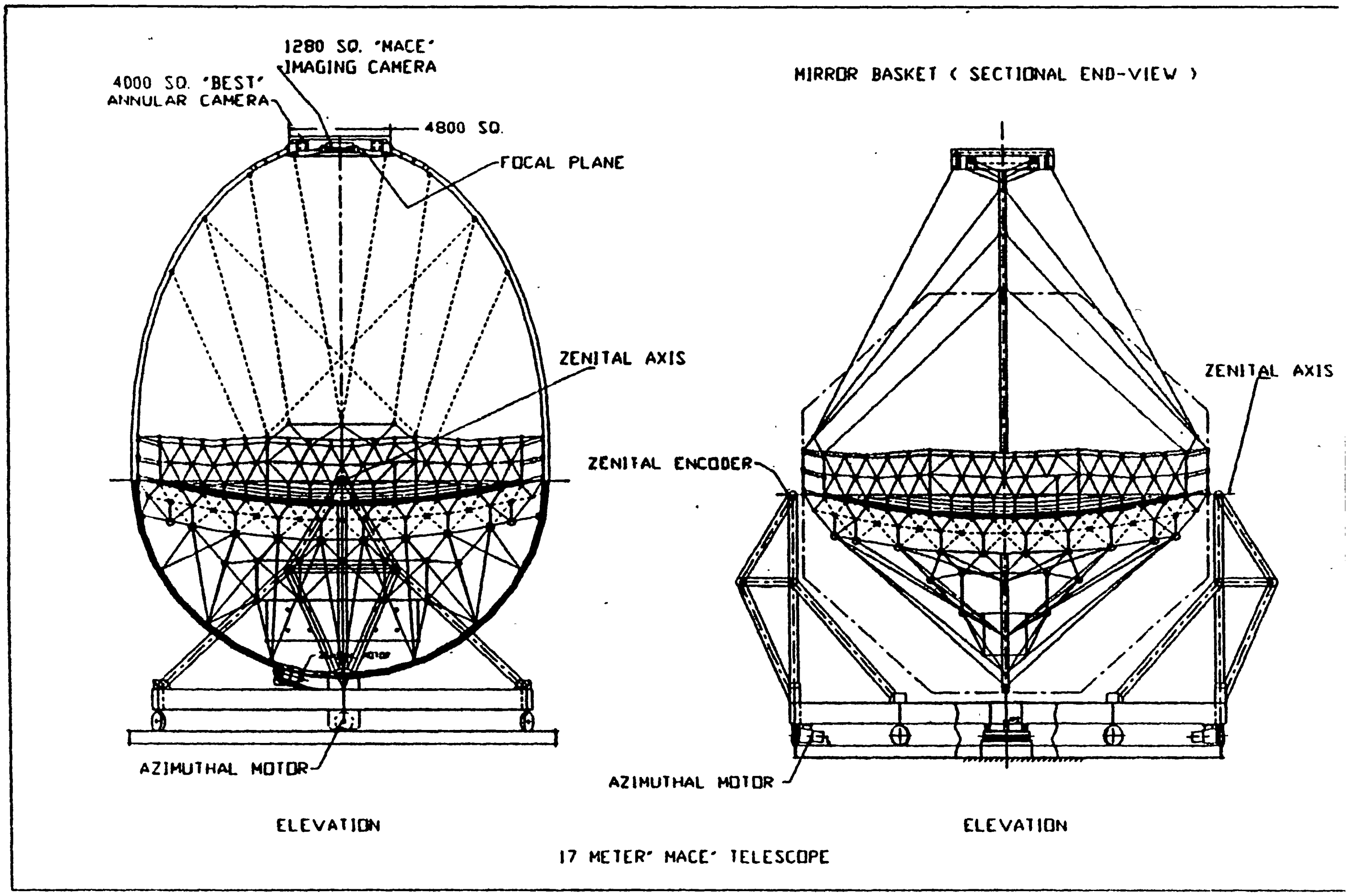

Fig. 1 : 17 Meter MACE Telescope with "MACE" and "BEST" Cameras

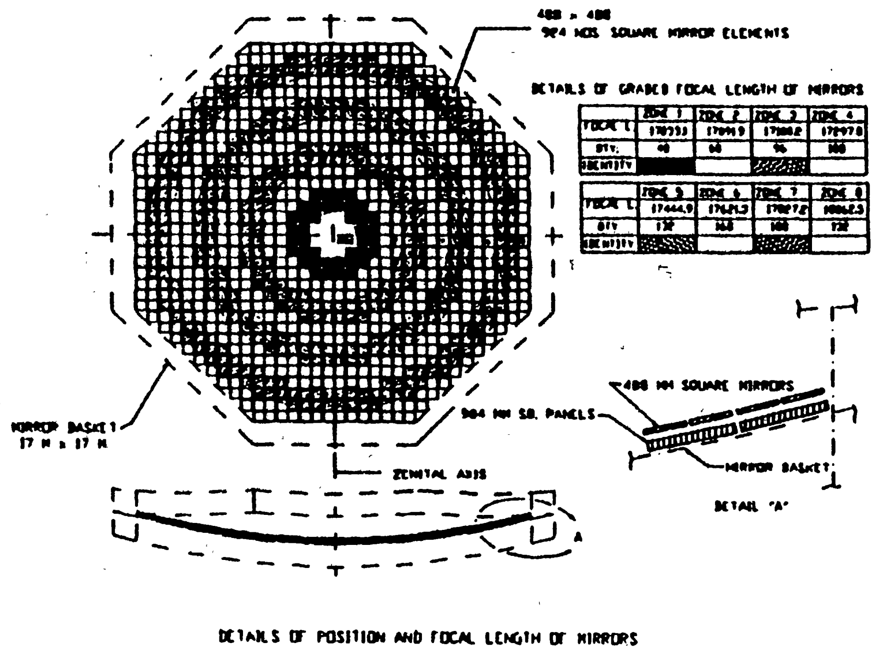

Fig. 2 (a) Position and Focal length of mirrors

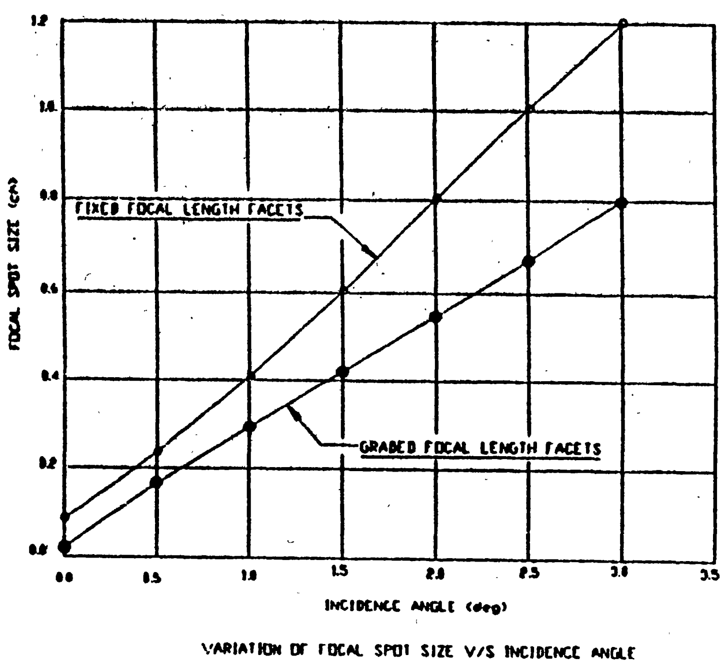

Fig.: 2(b) Variation of focal spot size

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/Mirror Basket, (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-paraboloid reflector, isochronous ≤ 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 ≤ arc –min. and (vi) Safe operation in wind speeds up to 60 km/hr with survival speed of up to 120 km/hr.

2.2 Tubular Frame Structure : Keping in mind the economics, feasibility and fabrication-cum-assembly considerations, we are planning to use steel for the tubular frame structure of the MACE Telescope. It is a 3 layer tubular structure forming a 17 meter octagonal shape. The top most layer of tubular members form a square grid of 1000 mm sides, to support 984 mm square mirror support panels. Second (middle) layer of tubular members, at a 707 mm distance from top most layer, forms a square grid of 1414 mm sides rotated by 45^0 wrt. the grid of top layer. Similarly bottom layer members at a distance of 1000 mm from middle layer form a square grid of 2000 mm sides, symmetric wrt. the grid of top layer. There are two stiffening rings at the edge of the octagonal mirror basket frame, each of 1000 mm height.

2.3 Mirrors : The mirror facets, 960 nos-488 mm square in size., are proposed to be made up of high-reflectivity, diamond-turned Aluminium sheets which are backed up with Aluminium honeycomb panels for the desired structural rigidity. Each mirror facet will use a 5 mm thick sheet of 6063 – Te Aluminium alloy, machined on a CNC diamond turned machine, fixed on a sandwitch, 488 mm square, honey-comb panel 27 mm in thickness (with 1 mm thick top and bottom plates of 3003 Al alloy). A set of four individual mirror facets will be aligned and fixed on a 1 meter x 1 meter, 50 mm thick, composite panel made up of aluminium honeycomb structure, sandwitched between two aluminium cover plates. The mirror panel will in turn be fixed to the telescope's tubular 3-D space frame with three point supports (one fixed support with single ball joint and two nos. precision actuator operated, supports with required ball and pin joints). An arrangement to heat the mirrors, to prevent conensation of moisture, is also to be provided.

The focal lengths of the mirrors, vary from 17 meter (for central mirros) to 18.0 meter (for outer most mirrors) with graded variations with increase in the radial distance. In all 8 different focal length mirrors will be used, to obtain the desired focal spot size.

2.4 Active Mirror Control : A laser pointer fixed at the centre of each mirror panel, directs the laser beam towards the focal point, when the telescope's optical axis is vertical. As telescope rotates about the zenithal axis, the deflections of the joints of 3D space frame of Mirror Basket result in deviations in the direction of laser pointer (corresponding to the tilt of the Mirror panel). A CCD camera (at centre of mirror basket) records this deviation, after every 10 minutes, and gives inputs to stepper motor drivers / actuators, which form a part of Active Mirror Control (AMC) System to correct this deviation, so as to keep the size of focal spot within 8 mm (1.5 Arc-min.) and its location centered on the optical axis.

2.5 Instrumentation Bay : All cables from the cameras (two cables for each PMT), mirror heaters and mirror alignment actuators will lead into the Instrumentation bay on the back side of the reflector / Mirror Basket. Signals received from PMTs are then to be transmitted to the Computers kept in the Control Room via wireless / microwave mode. A bare minimum number of the cables will be looped around the zenithal axis, to be taken on to a circular cable drag chain, to be fixed around the circular, Azimuthal track of the Telescope.

2.6 Present Status : Some of the presently on-going activities related to the MACE Telescope 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 studs, (iii) machining of mirrors to optical quality.

The mirror support panel as per the specifications is under procurement for trial assembly of the mirrors on the panels. Mirrors will be tested at test facility (to be set up at BARC) to test reflectivity and focal length of the mirrors. AMC (Active Mirror Control) system also will be tested / developed at BARC.

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 Telescope after reflection from the light collector surface. For these 'first-feel' simulation results, the MACE light collector is regarded as comprising 960 nos. spherical mirror facets of the size 0.49 x 0.49 meter 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 of 17 meter and (ii) graded focal lengths, gradually increasing from 17 meter to 18.062 meter (Fig. 2 (a)) as we go out from the light collector center to the outermost (8^{th} ring) of the light-collector. The results are shown in Fig. 2 (b) for both the cases as a function of the incidence angle, I. For the first case (fixed focal length), the linear spot-size is found to vary from 0.4-12 mm for I = 0.3 degree, 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 quasi-paraboloid surface, the advantage of isochronocity is retained by both of them.

References

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