MACE TELESCOPE

Commissioning Activities

*K.K. Yadav and MACE Project Team

The MACE project was proposed as SUB-TeV Light Experiment (SUBTLE) with the motivation of setting up an international class facility for the high energy gamma-ray astronomy incorporating, both, front-line basic research and technology spin offs. The Himalayan Gamma Ray Observatory (HiGRO) collaboration was formed involving BARC, Mumbai, IIA, Bengaluru, and TIFR, Mumbai in view of the magnitude and complexity of the MACE telescope. The main objective of the HiGRO collaboration was participation in the design, and installation of the MACE telescope at Hanle. An appropriate astronomical site for gamma-ray telescopes should be as follows.

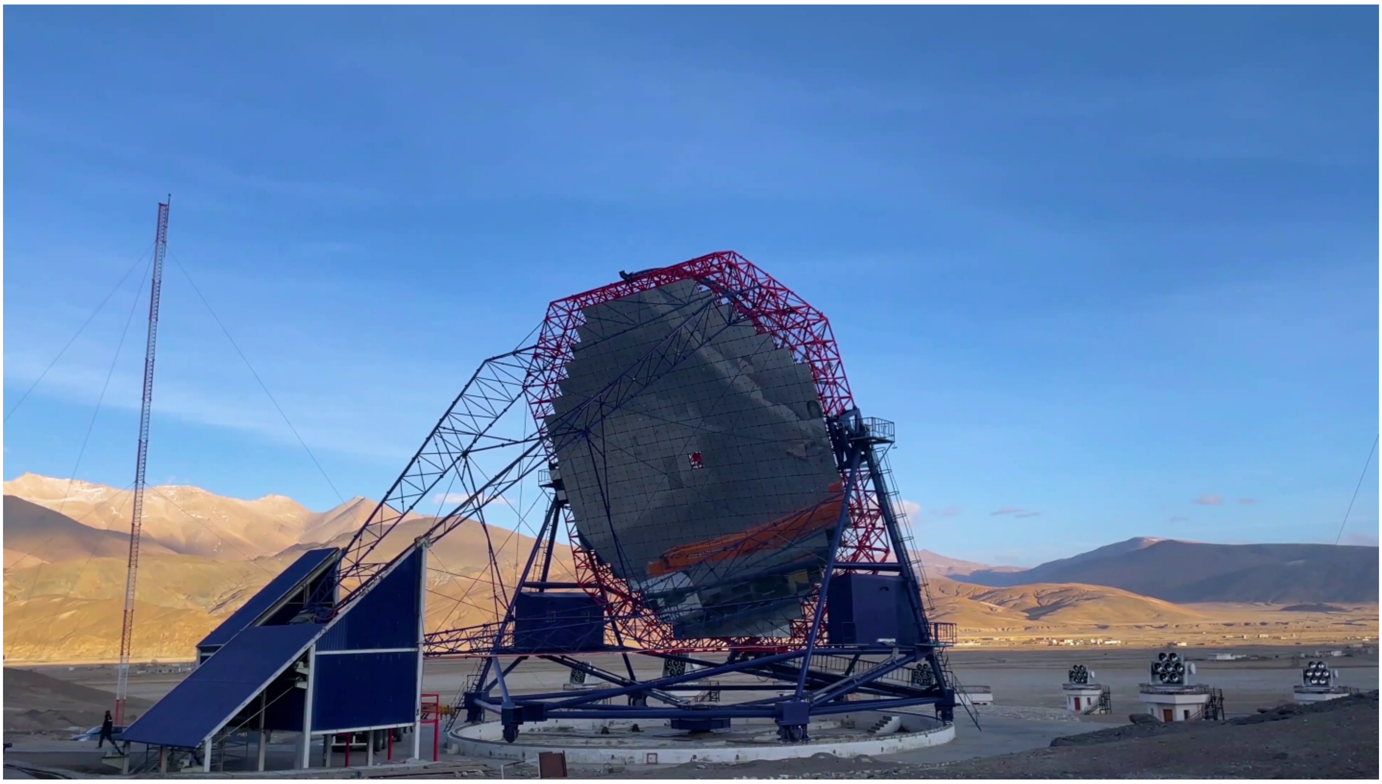
- Located at moderate altitude, preferably above the inversion layer.
- Characterized by the very good geological and geotechnical conditions (seismic activity, vibration transmission properties, mechanical properties of the soil).
- Equipped with good transport facilities, electricity and water supplies.
- Characterized by an atmosphere with excellent transparency to visible light i.e. minimum Rayleigh and Mie scattering, a very low level of humidity, low wind speed, low cloud coverage, low amount of dust in air and chemical pollution.
- Free from the snow fall and exhibit moderate temperature.
- With minimum possible level of natural and man-made light pollution i.e. dark nights, and low order of atmospheric turbulence in order to enable a maximum response for the highly inclined extensive air showers.
- Cloud free during dark nights and with negligible annual rainfall or precipitation.
- Characterized by the lowest strength of geomagnetic field.

Subject to the above criterion, Hanle (Longitude 78.9°E, Latitude 32.8°N, Elevation 4.27 km above the mean sea level) location in the high altitude Himalayan desert region of the Union Territory of Ladakh had been identified as the best astronomical site in the country for high energy gamma-ray astronomy from the ground using imaging Cherenkov telescopes. The Ladakh region, with numerous high altitude sites in the range 4 km to 5.6 km, is emerging as a potential hub for astronomical activities in India as it is found to satisfy various criteria to establish a ground-based astrophysical observatory. The Indian Institute of Astrophysics (IIA) took lead role in developing the new field station at Hanle under the mentorship of a national advisory committee consisting of many eminent scientists under the chairmanship of Prof. K Kasturirangan and a project management board headed by Prof. Yash Pal. This has been named as the Indian Astronomical Observatory (IAO). It compares with the Mauna Kea observatory at an altitude of 4.2 km in Hawaii.

Development and Installation Activities

Hanle site for the MACE telescope is located at a road distance of about 250km south-east of Leh, the only major city in the Union Territory of Ladakh. It was identified as a superlative astronomical site in 1992 by a team of astronomers from IIA for optical and infrared observations. This site is not affected by the two monsoons as it receives an annual precipitation of less than 10%. This has the distinction of being among the driest, calmest and darkest astronomical site at highest altitude in the world. It also has accessibility by paved roads round the year from the Leh city. The extreme climatic conditions with low oxygen level (~ 65%) and temperature ranging from -30°C to +30°C pose challenge to the regular human activities at the Hanle site.

The initial activities related to the site development for installation of the MACE telescope were profited from the existing infrastructure of the HAGAR (High Altitude Gamma Ray) telescope array operated by TIFR Mumbai and IIA Bengaluru since 2008. Being a remote location, the Hanle site is not connected to any power grid. Therefore, installation of a 240 kW solar power station was first completed at Hanle in order to fulfill the power requirements of the observatory. After the successful start of the solar power station, activities related to the construction of a place of stay for the field staff and control room for the telescope operation were started. The foundation structure of the telescope consisting of a circular rail track of 27m diameter with RCC foundation and a central circular beam was built for supporting the telescope weight and its drive system. It was followed by the installation of first layer of the alidade structure connecting the six equally spaced wheels and the central pintle-bearing. Concurrent trial of proof assembly of the mechanical structure was successfully completed at Electronic Corporation of



▲ MACE telescope at Hanle in the Union Territory of Ladakh.

India Limited (ECIL), Hyderabad. The camera electronics in the camera enclosure was also tested at ECIL, Hyderabad. Functionality of the MACE servo system with all its components was also tested and verified at ECIL by tracking a bright star **Id99** for eight hours. After being satisfied with the performance of the major subsystems of MACE, the mechanical structure was dismantled and transported to Hanle along with other subsystems of the telescope. On-site installation activities related to the various subsystems of the telescope were immediately started. Fine tuning of alignment of mirror facets on the 356 honeycomb panels was undertaken on the ground before mounting them on the telescope basket. Subsequently, all the panels were mounted on the basket along with the linear actuators. The servo system parameters were optimized and tuned after all the mirror panels had been assembled on the basket. All the 356 mirror panels were aligned through an active mirror alignment control system to obtain a single quasi-parabolic optical reflector of 21m diameter. Images of the Pole star and other bright stars were captured at different elevations to characterize the optical system and point spread function of the telescope. The fully wired 1088 pixel camera along with the associated electronics and data acquisition system was finally mounted on the focal plane of the telescope. The fully assembled MACE telescope along with a dedicated on-site control room was made ready in October 2020.

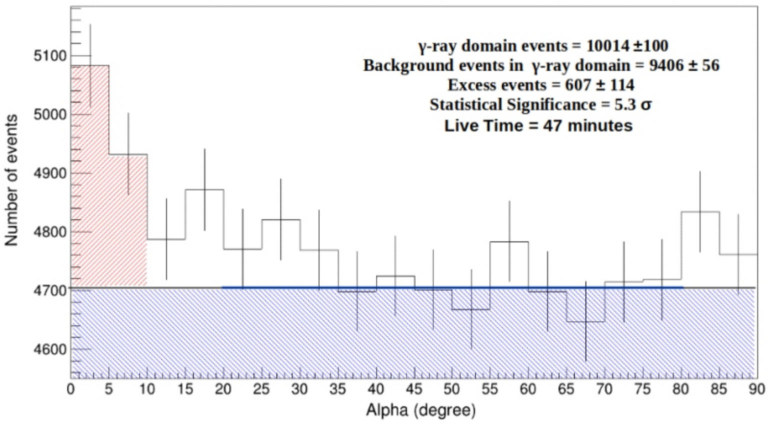
First Light and Commissioning

Activities related to the final commissioning of a large field instrument like MACE are generally driven by a number of practical goals that mainly include: (i) ensuring the compliance of various subsystems of the telescope and safe operations, (ii) verifying the scientific requirements and design specifications of the telescope particularly bending, mispointing and optical point spread function, (iii) fine-tuning the telescope operating parameters on the basis of scientific performance, and (iv) simplification of the control routines. Initially, some limited night observations were carried out in order to gain knowledge and confidence for smoothly running the telescope in future. Subsequently, the telescope was operated for longer periods during dark and moonless nights as part of technical and engineering trial runs of its different subsystems.

After completing the engineering trial runs of more than 350 hours, the MACE telescope was finally pointed towards the standard candle Crab Nebula (a steady source of broadband electromagnetic radiation in the Milky-Way Galaxy) on the night of 1st April, 2021 for a period of about 1 hour. The data collected on Crab Nebula was analyzed using the standard tools of the MACE data Analysis Package (MAP) software. A well-known procedure to extract the gamma-ray signal from the huge cosmic ray background is to plot the frequency distribution of a parameter, called, Alpha. The parameter Alpha is defined as angle between the major axis of recorded image and line connecting the image center of gravity with the source position in the camera plane (which is generally assumed to be the camera center). The Alpha-distribution for gamma-ray like events coming from the direction of a point source is expected to show a peak at smaller Alpha-values, whereas, it is flat for the isotropic background of cosmic ray events across the entire range from 0° to 90°. Detailed Monte-Carlo simulation studies are performed to establish gamma-ray selection criterion for observations

▲ A 240kW solar power station operating at Hanle, UT of Ladakh.

▲ MACE control room facility situated at Hanle site.



▲ PRELIMINARY results obtained from the first successful detection of the standard candle Crab Nebula with the MACE telescope on the night of April 1, 2021.

with the IACTs. In the case of MACE, Alpha $\leqslant 10^\circ$ and $20^\circ \leqslant$ Alpha $\leqslant 80^\circ$ are defined as the gamma-ray or signal domain and background region respectively.

The number of gamma-ray like events is then calculated by subtracting the expected number of background events from the signal domain events. Preliminary results suggest that a total of about 10014 events have been detected in source region wherein about 9406 events are contributed from the isotropic cosmic ray background. This indicates that approximately 607 very high energy gamma-ray like events were observed from the direction of Crab Nebula in a live time of ~ 47 minutes by the MACE telescope. It is equivalent to a signal to noise ratio of 5.3 and corresponds to the detection of plausible gamma-ray signal from the standard candle at 5.3σ statistical significance level. These initial results mark the first successful light of the MACE telescope. Similar results were also obtained from the subsequent observations of the Crab Nebula at different occasions with the MACE telescope. On the basis of successful detection of statistically significant gamma-ray emission from the standard candle, the MACE telescope was officially commissioned in September 2021. These results from the first light and subsequent observations have been used to validate the performance of the telescope and its calibration.

Future Outlook

The MACE telescope is an exemplary outcome of the spirit of 'Atmanirbhar Bharat' as its various subsystems have been designed and developed within the country. It is deemed to unveil the mysteries of the Universe such as the violent and very energetic processes in the distant galaxies having super massive black holes at their centers, neutron star systems in our Milky-Way Galaxy among others.

The Authors are from Astrophysical Sciences Division of Bhabha Atomic Research Centre, Trombay, Mumbai.

*kkyadav@barc.gov.in**