Exploring fundamental nature of dark matter...

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The origin of cosmic rays is one of the major unresolved puzzles in modern science. Cosmic rays, discovered by Victor Hess[1] in 1912, are the energetic particles, primarily dominated by protons, that move through interstellar and intergalactic space with the speed nearly the speed of light. The energy of cosmic rays span between tens of MeV to 10^{20} eV. The measured spectrum of cosmic rays is a power-law which characterizes the non-thermal behavior. The fundamental questions that remain unanswered about cosmic rays are: (a) where are they produced and (b) how are they accelerated to such high energies? Even though the direct detection of the cosmic rays is one of the major experimental approaches to study the spectrum and chemical abundance of cosmic rays, but it can not give enough understanding of the sites and mechanism of the particle acceleration. This is due to the fact that the presence of magnetic field in the interstellar and intergalactic space make cosmic ray particles to deviate from their original path losing the information of the site of their origin. But gamma-ray astronomy can provide a solution to this. The highly relativistic cosmic ray particles can interact with the ambient magnetic field or photon field or matter at the site of their origin to produce very high energy gamma-rays. Very high energy (VHE) gamma-rays thus produced at the source can reach the earth without any deviation carrying the information of their origin. The study of VHE gamma-rays can reveal the hidden information about the cosmic rays, their interactions with the ambient field and the possible acceleration processes.

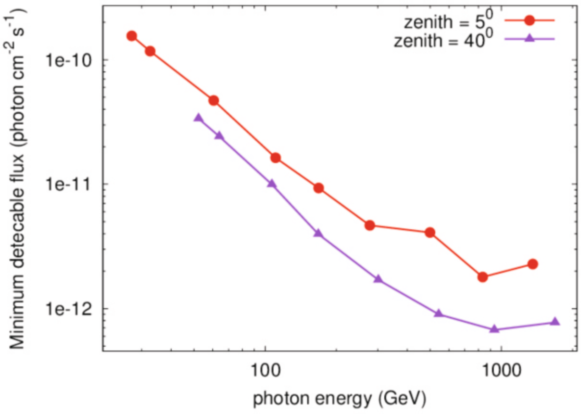
With the advent of imaging atmospheric Cherenkov telescopes (IACT) VHE gamma-rays have been detected from around 250 sources[2] belonging to a variety of source classes, hence different cosmic accelerators, which can produce cosmic rays. But many of these detection have challenged our understanding about the physical processes responsible for the particle acceleration and the gamma ray emission processes. The questions raised by these discoveries can be answered only with increased number of sources in VHE band. Therefore, we need more IACTs with lower energy threshold and higher sensitivity. The recently commissioned imaging atmospheric Cherenkov telescope MACE at Hanle would give us the opportunity to explore VHE gamma-ray sources extensively. In the following sections we discuss the science objectives, which can be pursued with the MACE telescope.

Sensitivity of MACE Telescope

One of the most important parameters which decides the performance of an IACT is its sensitivity. The minimum gamma-ray flux that an imaging Cherenkov telescope can detect at 5s level in 50 hrs is known as the sensitivity. The sensitivity of the MACE telescope for low and high zenith angles has been understood. In the low zenith angle range (up to ~25^0), the MACE telescope can detect ~ 2.7% of the flux of Crab nebula at 5s level in 50 hrs. The direct comparison of the spectra of sources detected by space-based Fermi telescope in 10 GeV–2 TeV energy range with the sensitivity of the MACE telescope gives an initial number of sources, which can be seen by the MACE. Considering the sources from the third Fermi high energy catalog (3FHL) it is found that nearly 55 sources can be observed with the MACE telescope. Note that these sources can be detected by the MACE telescope in less than 50 hours of observations whereas Fermi telescope took few years of observation.

Understanding the Origin of Cosmic Rays

As it is already mentioned that the field of gamma-ray astronomy was born to probe into the origin of cosmic rays, our first target is to observe the possible sources of cosmic rays and measure their spectra with better precision. It is generally argued that the cosmic rays below 10^{15} eV are produced in the Milky Way galaxy. It was first argued by Baade and Zwicky in 1934[3] that the supernova remnants (the debris produced in the demise of massive stars moving with supersonic speed through interstellar medium) are the most suitable

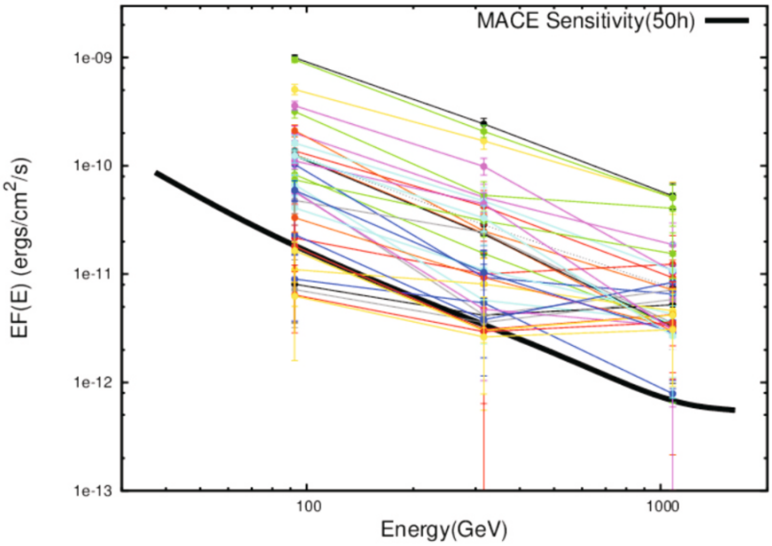


▲ THE SENSITIVITY of MACE Telescope for Low and High Zenith Angles.

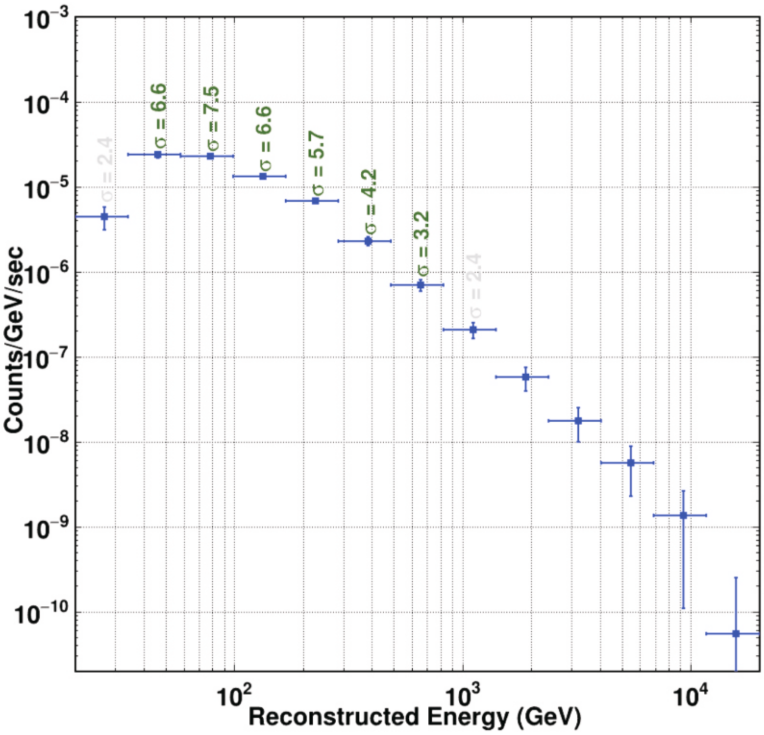
candidates which can accelerate charged particles to relativistic energies. Supernova remnants are already seen by different gamma-ray telescopes and their spectra are measured. But the observed spectra are generally modeled by considering the gamma-ray emission through inverse Compton scattering of soft photons off the relativistic electrons produced in the supernova shock by first order Fermi acceleration process. In some cases the observed spectrum can be explained by the gamma-ray emission due to the decay neutral pions produced in the proton-proton collisions. In such a scenario the relativistic protons are considered to be produced in the supernova shock. The ambiguity in the interpretation is primarily due to the insufficient amount of data to construct the spectrum. The MACE telescope with its very low threshold and high sensitivity can measure the spectrum with higher precision and the ambiguity in the spectral modeling can be addressed. Simulated spectra of supernova remnants Crab nebula and Tycho expected from MACE observation for greater duration of 10 and 50 hours, respectively was ascertained. It is important to note that the Crab nebula has already been detected by the MACE telescope immediately after its commissioning. Work is in progress to determine the gamma-ray spectrum from the MACE data and it will be published elsewhere.

The other important class of sources to be studied by the MACE telescope is pulsar. Pulsars are rapidly rotating (spin period ~ 10s of millisecond) neutron stars with surface magnetic field ~10^{12} G. Pulsars are also considered to be the possible sites of particle acceleration. Fermi detected around 300 pulsars in MeV-GeV energy range while only four pulsars are detected in the GeV-TeV energy range. Due to the very low threshold energy of the MACE telescope the pulsars are one of the best candidates to study by it. Apart from the supernova remnants and pulsars, the micro-quasars are also to be observed by the MACE telescope. Micro-quasars are the radio-bright black hole x-ray binary systems consisting of a normal star and a black hole. The simultaneous observation of micro-quasars in gamma-ray with MACE and in x-rays with AstroSat can shed light on the physics of disc-jet connection in black hole sources.

To understand the origin of cosmic rays above 10^{15} eV it is important to study active galaxies whose nucleus out shines the rest of the galaxy (AGN: Active Galactic Nuclei)[4]. For instance, a normal galaxy like Milky-Way generally contains 10^{11} sun like stars and hence its over all luminosity will be 10^{44}erg/sec (Solar luminosity 10^{33}erg/sec). The luminosity of AGN therefore exceeds 10^{44}erg/sec. They are further classified based on their spectral and morphological properties. Major class of AGN which are detected in VHE gamma-rays fall under the category of blazar, where the emission arises from a relativistic jet pointed towards the earth. Blazar jets are sites where particles are accelerated to ultra-high energies by relativistic shock or by magnetohydrodynamic turbulence, or by both. Hence they are the emitters of GeV-TeV radiation, which can be studied by the ground-based Cherenkov telescopes.

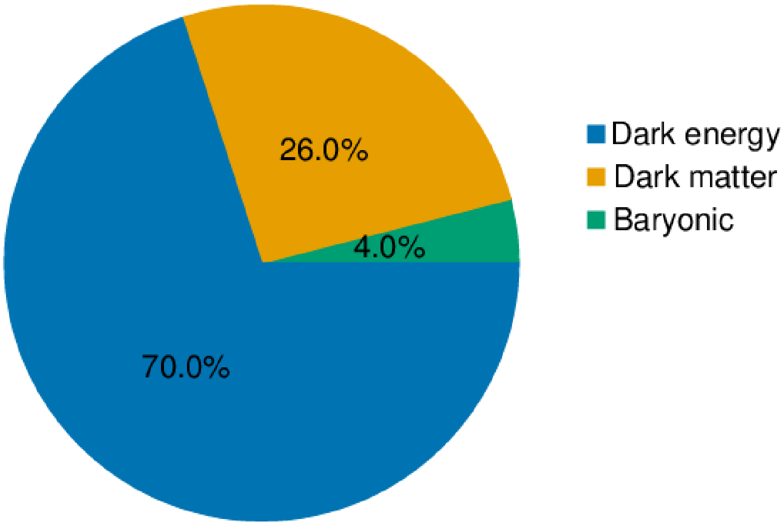


▲ REPRESENTATIVE PLOT SHOWING comparison of Fermi Spectra of Different Sources with MACE Sensitivity. Colored Lines are the Spectra of Different Sources as Observed by Fermi Telescope.



▲ THE SIMULATED SPECTRA from Crab Nebula (Upper) and Tycho (Lower) Supernova Remnants expected to be seen by the MACE Telescope.

The very high energy emission in blazar is generally interpreted as inverse Compton process where relativistic electrons scatter off low energy photons to gamma ray energies. But there is still an ambiguity in understanding the gamma-ray emission mechanism for this type of sources. The emitted gamma-rays can be generated by the decay of neutral pions produced in photo-pion interaction in the relativistic jet. To resolve this uncertainty the VHE spectrum from blazars should be measured precisely and that can possibly be done using the MACE



▲ CONSTITUENTS of the Universe.

telescope. From the precisely measured spectra from blazars, one can study the particle acceleration process as well as the radiation emission process in very high energies in a relativistic jet.

Probing the Extragalactic Background Light (EBL)

Study of blazars in VHE, besides providing information about the particle acceleration and radiation emission processes in relativistic jet, also has cosmological importance. VHE emission from distant blazars is significantly attenuated due to the pair production process upon interacting with the EBL. EBL is the diffused background radiation exhibiting peaks at IR and UV wavelengths with the main contributors being the cosmic dust and cumulative galactic emission[5]. The IR component is the relic radiation initially originated during the structure formation epoch of the Universe and it is continuously reprocessed by dust absorption and re-emission.

On the other hand, the UV component of the EBL arising from the galaxies carry the history of the star formation rate during the cosmic evolution. Direct measurements of EBL are heavily hampered by our own galaxy emission and the zodiacal light. Hence, indirect methods involving galaxy counts and cosmic computer simulations are employed to estimate EBL. Conversely, one can study the attenuation of VHE photons from distant blazars to estimate the EBL column confined between the source and the observer. This technique has been widely recognized as an alternate measurement of EBL and is even used to establish the cosmic EBL models.

The result of EBL induced attenuation of VHE emission from blazars is that the VHE spectral slope of distant blazars will be steeper than the nearer ones. Recent correlation study between the VHE spectral index of an ensemble of blazars with their redshift has confirmed this inference. Observation of far-off blazars with redshift ~1 or more can give us better estimates of the EBL which has direct bearing on the evolution of our Universe. The MACE telescope can achieve this by measuring the spectrum of distant blazars with greater precision.

Study of Dark Matter

The study of cosmic microwave background has unequivocally established that the universe consists of observable matter and energy (~ 4%), dark matter (~ 26%) and dark energy (~ 70%). The nature of dark matter and dark energy are completely unknown. Presently, the theoretical studies suggest that dark matter is possibly made of elementary particles whose nature is not yet known. But those particles are massive with mass in the range of GeV-TeV, stable and electrically neutral. They are also nonbaryonic. One possible candidate is weakly interacting massive particles (WIMP)[6]. Theoretical models predict different annihilation and decays channels of WIMP which can produce gamma-rays[7]. Therefore, gamma-ray astronomy can be used for the indirect detection of dark matter. The MACE telescope will play an important role in the study of dark matter. The dwarf spheroidal galaxies (dSphs) are the best targets to study dark matter[8]. Dwarf spheroidal galaxies are the satellite galaxies of the Milky Way galaxies. These galaxies have very high mass-to-light ratio because of the low star content. Because of that the contribution of gamma-rays from other sources will be quite low giving an opportunity to observe gamma-rays produced by the dark matter. Apart from the science objectives, MACE will be helpful to observe gamma-ray bursts (GRBs) in very high energy gamma-rays.

Conclusion

In conclusion, the MACE telescope built by the Astrophysical Sciences Division, BARC, is a state of the art facility, which would surely stimulate us with new discoveries and enrich us with the new knowledge about the cosmos.

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