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Historical Aspects of Gamma ray Astronomy

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Abstract.

Over the entire 20th century, Cosmic Rays proved to be the watershed of fundamental knowledge from which poured out several streams that made us familiar with aspects of the universe that could never have been known through optical and radio astronomies alone. Cosmic ray interaction studies opened up the field of elementary particles and high energy physical processes. Gamma-ray astronomy enabled us to study celestial environments characterised by the dominance of high energy particles and their interactions with matter, magnetic and electric fields in the neighbourhood of these special environments. While neutrino astronomy is still in its infancy, it has the potential of becoming the most exciting field of study in the current century.

Gamma-ray astronomy has had a chequered career. In the early part of the 20th century, Millikan proposed that cosmic rays are merely gamma rays. This was disproved by Compton, through the establishment of the latitude effect. The soviet astrophysicist Shklovskii pointed out at the III International conference on cosmic rays held at Guanjuato, Mexico, the possibility of supernova remnants like the Crab Nebula being sources of TeV gamma rays. This was based on his realisation that the high degree of polarized light from the Crab could be due to Synchrotron emission by TeV energy electrons spiralling round the filamentary magnetic fields of the nebula. He argued that the same mechanism that accelerated electrons could also accelerate the protons which through their interaction with the surrounding matter generate pi-zero measons that would immediately decay into gamma rays. However, the efforts by the soviet experimentalists, who used the night air cerenkov technique for detection of the TeV gamma rays, proved negative; only upper limits could be set on the fluxew of TeV gamma rays from several of the SN-remnants; the negative results were first reported at the 7th ICRC held at Jaipur, India in 1963.

High energy gamma ray astronomy had a remarkable revival with the discovery of Pulsars in 1967 and their identification with Neutron stars. The field has

thrived since then and has been extended even to the PeV range. Beginning with 1965, gamma ray astronomy in the energy range MeV to tens of GeV has also been successfully pursued with balloons, and satellites. The most perplexing in this energy range has been the discovery of the Gamma ray bursts.
In the keynote address the historical aspects of this field will be covered with some references to the work in India.

Right from the time of Coulomb, famous for his pioneering experiments in the late 18th century, a mystery had persisted concerning the persistent discharge of electricity from a charged well insulated metal sphere. With the discovery of radioactivity towards the end of the 19th century and the recognition of the phenomenon of ionization of the surrounding air by the radioactive radiations it had been thought that this leakage of electricity might be due to the ionization of the air surrounding the metal sphere caused by the radioactive radiations of the earth., the most penetrating among the radioactive secondaries being gamma rays. If this was the true explanation then the intensity of ionization should decrease with distance for the surface of the earth. Victor Hess in 1912 conclusively proved on the basis of his balloon experiments that the cause of ionization was not the radioactivity of the earth, but was an extraterrestrial, extrasolar radiation, that came from depths of space. The name Cosmic Rays was given to this radiation by Millikan. It turned out that this radiation was pouring in day and night at all places and practically from all directions. It was very complex in character- there were two components, one penetrating and the other easily absorbed in a few millimeters of lead. The soft component occasionally poured in as a shower of several charged particles. To sort out the various characteristics of this mysterious radiation and understand the physical processes behind them took several decades of effort by scientists all over the world. The ingenious experiments that had been setup to analyse the properties of these radiation led to very rewarding results - the discovery of new elementary particles and new high energy processes. The anti-particle of the electron, the positron, the muon, the pion the Kaon and the Hyperon were all discovered in 'cosmic rays and ushered in the era of elementary particles pursued with cosmic rays and later with higher and higher energy accelerators.
Of particular interest to cosmic ray phenomena in the atmosphere has been the recognition of the spontaneous chain reactions interconnecting the particles - the charged pions decaying into muons and neutrinos, the muons into electrons and neutrinos, the neutal pions into gamma rays, the Kaons into pions and also some times into muons etc.
These intricate connections, coupled with theoretical developments of electromagnetic processes, bremstrahlung, pair production and most importantly meson production. The soft component and the associated showers were identified with cascade processes resulting in the creation and annihilation of electron-position pairs, the electrons and gamma rays arising in the first instance by

the spontaneous decay of the muons and pi- zero mesons. The penetrating component was identified with the charged muons resulting from the decay of charged pions. It took quite some effort to identify the nature of the primary that gave rise to all these secondaries encountered in the lower atmosphere. Before the recognition of the role of meson production in the atmosphere, a contrversy had raged between Millikan and Compton about the nature of the primary radiation incident on top of the atmosphere. Compton, through a series of measurements at different latitudes was convinced that the primaries are charged particles perhaps electrons and Millikan on the otherhand had held that the primaries are high energy γ-rays that had their origin in the process of synthesizing heavy elements in the outer space. Compton won finally. However the primaries were later identified as protons and stripped heavy nuclei. These developments on meson production and decay phenomena and cascade processes that resulted from cosmic ray studies in the atmosphere, opened up the possibility of there being celestial gamma ray sources induced by the impact of high energy cosmic rays. One could also expect a diffuse component of gamma ray from the collisions of cosmic rays with interstellar matter.

Because of the low flux of these celestial gamma rays and the poor efficiency of gamma ray detectors, experimental detection had to await the satellite era for actual detection. The gammarays from the milky way were first detected in the instruments on OAO satellites in the early 60s by the MIT group.

The real boost for prospects in high energy gammaray astronomy came from a rather unexpected direction. Optical astronomy had revealed that the visible light from the crab Nebula is highly polarized. The Soviet astrophysicist Shlovsky had suggested that this polarized light could be due to synchrotron emission by high energy electrons gyrating round the magnetic fields of the filments of the nebula. He figured out that with an assumed magnetic field of 10^{-3} Gauss, to account for the extent of polarization observed, there had to be present electrons of Tev energy in the nebula. If this was so, then there must be some mechanism operating in the supernova remnant that could accelerate electrons to such high energy. If electrons could be accelerated, there was no reason why protons could not be accelerated by the same mechanism. Such high energy protons would interact with the matter of the nebula and give rise to the production of pions and the neutral pions would instantaneously decay into gamma rays. Thus, argued Shlovsky that Crab could be a source of Tev gamma rays. This scenario was exciting from many points of view. Firstly, many of the supernova remnant could be the sources of gamma rays in the Tev range, and they would naturally also be the sources of cosmic rays of still higher energy. Though this work of Shlovsky had appeared in Soviet Journals earlier, it became known to the western world for the first time at the Gaunjuato cosmic ray conference in Mexico in 1954. Following this conference, several experimenters started looking for gamma rays from Supernova remnants. In the early 50's, PMS Blackett had suggested the possibility of detecting cerenkov emission by the passage of charged particles through the atmosphere. This had been experimentally established by Jelly and his collaborators using photomultpliers at the foci of large area searchlight mirrors. The soviet scientists

Chudakov, Stepanion and others used this method of detecting cerenkov light from extensive air shower secondaries to look for Tev gamma ray emission from several supernova remnants, including the Crab Nebula. The first upper limits from several of them were reported at the 7th international conference on cosmic rays held at Jaipur in 1963.

The interest in Tev gammaray astronomy was revived in 1968 with the discovery of pulsars in radioastronomy particularly with the identification of the Crab Nebula as one of the pulsars. The neutron star nature of the pulsar in the nebula meant that there could be in the neighbourhood of the star magnetic fields of the order of 10^{12} gauss or more, which was just the kind of environment that could accelerate particles to very high energies. It was also realized that if the Tev gamma rays were also pulsed then there would be an additional advantage of lower background and therefore lower threshold energies as well and increased flux for detection. The hunt for pulsed Tev gamma rays from pulsars started in many laboratories in the world.

It so happened that in our Ooty cosmic ray laboratory, we had developed the air cerentov technique for an experiment to distinguish between protons and pi-mesons in the energy range 10-40 Gev, to look for possible differences in the nuclear interaction characteristics. Above a multiplate cloud chamber, we had mounted an air cerenkov counter for this purpose and below the cloud chamber, we had a total absorption spectrometer to measure the energy. This triple setup was in operation in the early sixties before the CERN accelerator providing 30 Gev proton beams became operational. This familiarity with air cerenkov using searchlight mirrors came in handy in 1969 when we started setting up assemblies of searchlight mirrors for pulsed Tev gamma rays detection. The programme that started with just two mirrors has continued over the past 32 years and is now being pursued with an impressive array of 25 telescopes with 7 mirrors in each telescope and spread over 105 square meters. You will hear more about this PACT array and the latest results from the array by the members of the TIFR Pachmari Group.

Tev gammaray astronomy suffered for a long time from marginal signals despite increasingly larger and larger sensitive areas for cerenkov . light detection. With the development of the imaging technique by the whipple group, the field has made rapid progress and in the last few years the signals from even extragalactic sources like Markarian 501, and Markarian 421 have been convincingly detected. Several newer methods for discriminating between the background proton and heavy primary showers and the Tev gamma ray induced showers have been developed and these will be discussed in this seminar.

In India, in the 80's another Tev gamma ray array started operating in Gulmarg in Kashmir. The members of this group have how been responsible for setting up this very impressive very large scale complex of installations at Mt.Abu, which you will have the opportunity to visit and become familiar with.

In the early 70's a new dimension was added to the field of gammaray astronomy by the serendipitous discovery of celestial gammaray bursts in an experimental installation of sodium iodide detectors on a satellite and meant for the monitoring of nuclear explosions by different countries of the world. While a large amount of data has been accumulated on the gammaray bursts by several balloons and satellite experiments, the phenomenon remains a mystery. It is not even clear whether the bursts are of galactic origin or extragalatic. The efforts to identity the gammaray burst sources with other known objects like x-ray sources, pulsars, AGN's etc are being pushed with vigour. Sometime back repeated gamma ray bursts from the same direction created considerable excitement which however has died down.

One of the important lessons that we have learnt from the field of x-ray astronomy in the last few decades is not to ignore transient phenomena and treat them as trivial fluctuations. Many x-ray sources have shown low and high states of excitation, not necessarily periodic though quite a few of them turned out to be compact binary systems with one of the components being a neutron star or a back hole.

One of the enigmatic and perhaps also erratic high energy gammaray source has been Cyg x-3 which entered the catalog of astronomical objects in 1966 as the brightest x-ray source detected by the first x-ray satellite UHURU. It was recognized as a binary system with a period of 4.79 hrs. A surprising feature was that though this source was a very weak source in the radio band of the electromagentic spectrum, occasionally it flared up by several orders of magnitude in intensity and remained in this bright state for several days. As early as 1972, the Crimean astrophysical observatory had recorded Tev energy bursts from this source on Sept 9, 19 and 22 of that year.

Further excitement was added concerning this source in 1983, when the Kiel Air shower Group in Germany reported observations of excess of extensive air showers of energy in the range of $10^{15} ev$ (Pev) from the direction of this source. The Kiel group results were also supported by the observations of the Haverah Park air shower group in U.K. whose array recorded showers of still higher energy. An anomaly however was that the number of muons recorded in the showers corresponded to proton induced showers than gammaray induced showers. These results were reported at the 18th International Conference on cosmic rays held at Bangalore in 1983.

Since 1983, Cyg x-3 has been another celestial source that has been under observation over a wide range of energies and even special international collaborations involving simultaneous observations in many energy bands have been carried out. Episodic bursts of activity in the Pev every range have been seen both at Ooty and KGF. A controversial, but very interesting observation has been the recording of very high energy muon bursts in underground detectors coincident with the bursting activity of Cyg x-3 in Jan 1991.

The SOUDAN group in USA which operates a protn decay detector in an underground station reported muon burst of energy greater than 0.7 Tev during the radio flare period of Cyg x-3 19th to 25th. Jan. 1991. The bursts were seen on the 20th and 23rd. Interestingly the KGF proton decay detector also recorded muon bursts of energy greater than 8 Tev on the 18th and 19th of January. The NUSEX group also reported bursts of energy greater than 5

Tev in their Proton Decay installation in Mont Blanc tunnel. These are all very rare episodic events and the progress in this field is bound to be very slow since the activity itself is of the order of one per year. One hopes for the presence of many other sources of this kind. Another flaring source in the Tev range that has been observed is Her x-1, which again was first detected as a binary x-ray source by UHURU. This source has three periodicities in x-rays - a 1.24s pulsar periodicity attributed to the rotation of a neutron star inside, a binary period of 1.74 days in which the neutron star goes round its companion and a 35 day period which modulates the x-ray intensity and is attributed to the precession of the neutron star or of the accreting disc. Since 1983, Tev emission has been reported by several groups. A spectacular increase in intensity in the Tev energy range for a period of 17 mins was recorded by the Pachmarhi group on April 11, 1986. With the Ooty Air shower array four well separated episodes of Pev emission were recorded during July-December of 1986. What is interesting is that the period in the Pev pulsed emission during April-Nov 1986 was distinctly different from that of the period in x-ray emission and agreed with other Pev observations during the same time.

While gammaray astronomy at all energies has made considerable progress in the past 40 years, many issues remain unanswered yet. The gammaray bursts are still an enigma. The methods of acceleration of charged particles which are the source of high energy gammarays are still controversial. I am sure that this Abu meeting will update us on the current status of the field and also educate us on installations based on new methodologies that are coming up in various laboratories in the world. I look forward to a great meeting in this wonderful serene surroundings.