radiation. In this talk I will try to give a flavour of these new astronomies by highlighting some recent results that have emerged in the areas of Tev ($> 10^{12}$ev) and Pev ($> 10^{15}$ev) astronomies pursued with specially designed installations on the surface of the earth and deep underground and point out the prospects in the emerging area of high energy neutrino astronomy.

Tev and Pev Astronomies:

Tev ($> 10^{12}$ev) and Pev ($> 10^{15}$ev) astronomies are pursued in two different ways : (i) through the recording of extensive air showers produced in the atmosphere with variety of detector systems at mountain altitudes and sea level (ii) through the recording of very high energy muons produced by the incoming radiation in the atmosphere with large area installations deep underground or under thousands of feet of water in the ocean.

The profile and the contents of air shower that developes in the atmosphere depends upon the nature of the incident high energy radiation. If it is a high energy photon then a pure electromagnetic cascade developes and if it is a hadron - a proton or a heavy nucleus, then a nuclear cascade developes and feeds energy into electromagnetic cascades through the production of π° mesons which in turn decay into γ-rays the progenitors of e.m. cascades. Some of the charged pions interact and produce more secondaries and the others decay into muons and neutrinos. There is therefore a distinct difference in the composition of particles at the observational level between photon induced showers and hadron induced showers. The pure electromagnetic cascades are expected to have a very low content of muons and much less of hadrons (See Fig.1).

In the case of Tev cascade the shower maximum is reached well before the observational levels of mountain altitude and sea level and the intensity of charged particles would be on the decline due to absorption effects. The shower particles chiefly the electrons and the positrons in passing through the atmosphere give rise to a considerable amount of cerenkov radiation; the maximum contribution comes from the shower maximum region. Because of scattering effects and the exponential nature of the atmosphere, the shower particles spread out laterally to several tens of meters by the time they reach the maximum. Consequently, the cerenkov pool of light that reaches the observational level would be distributed over an area of $\sim 10^4$ sq. meters or so. In the case of Pev hadron showers, the shower maxima are reached at mountain altitudes and the number of particles is much larger and it becomes feasible to record these charged particles themselves by means of scintillators.

The methods of observation of Tev and Pev showers are different. For Tev showers the atmospheric cerenkov radiation is used for detection. Large area mirrors mounted on either a single orientation platform or on several distributed platforms are used to focus the cerenkov light into a set of photomultipliers and the coincidence from several of them is used as the signal to record the shower. The entire assembly of mirrors is pointed in the direction of the source to be investigated and the orientation system is programmed electronically to track source for several hours. The

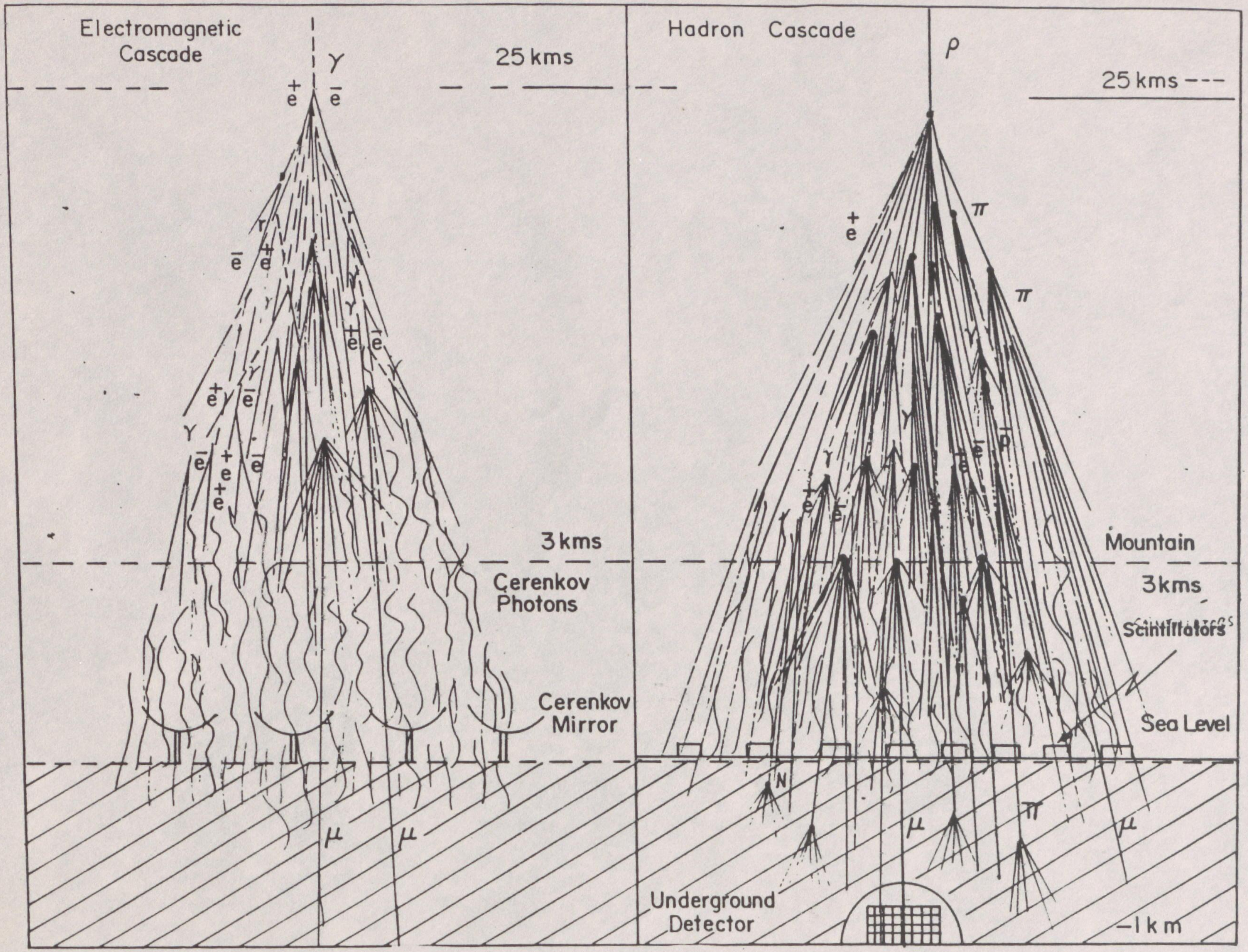

Fig. 1. Development of the pure electromagnetic and hadron cascades in the atmosphere. The main difference is in the content of nuclear active and muon components which are appreciable in the hadron cascades. Detection in the Tev domain is done through the atmosphere Cerenkov radiation in the Pev domain through charged particles.

cerenkov technique is feasible only during moonless, cloudless nights. Therefore the observation period is restricted. The technique is found to be most effective for the energy range 10^{11} - 10^{13}ev.

In the case of Pev showers, the registration is done by an array of scintillators and the time of arrival of the shower front at the different scintillators is utilised to determine the direction of arrival of the shower which can be done to an accuracy of a few degrees. The KGF air shower array[1] which is in operation for several years and which is typical of such air shower recording systems is shown in Fig. (2). The air shower arrays operate from about 10^{14}ev to 10^{20}ev depending on the size of the installations.

A serious problem for Tev and Pev astronomies in which the interest is in recording the signals from individual sources, is the overwhelming background due to showers produced by the isotropic cosmic radiation in the atmosphere. Inspite of a steep zenith angle dependence at the observational level, and limited aperture for acceptance of showers the background is still large.

Recently the Whipple Observatory Group[2] in USA, has succeeded in reducing this background by a very large factor by developing an Imaging Cerenkov Technique which enables them to distinguish between hadron induced and photon induced showers. The principle of the imaging technique is illustrated in (Fig.3). In the case of Pev showers the distinction between

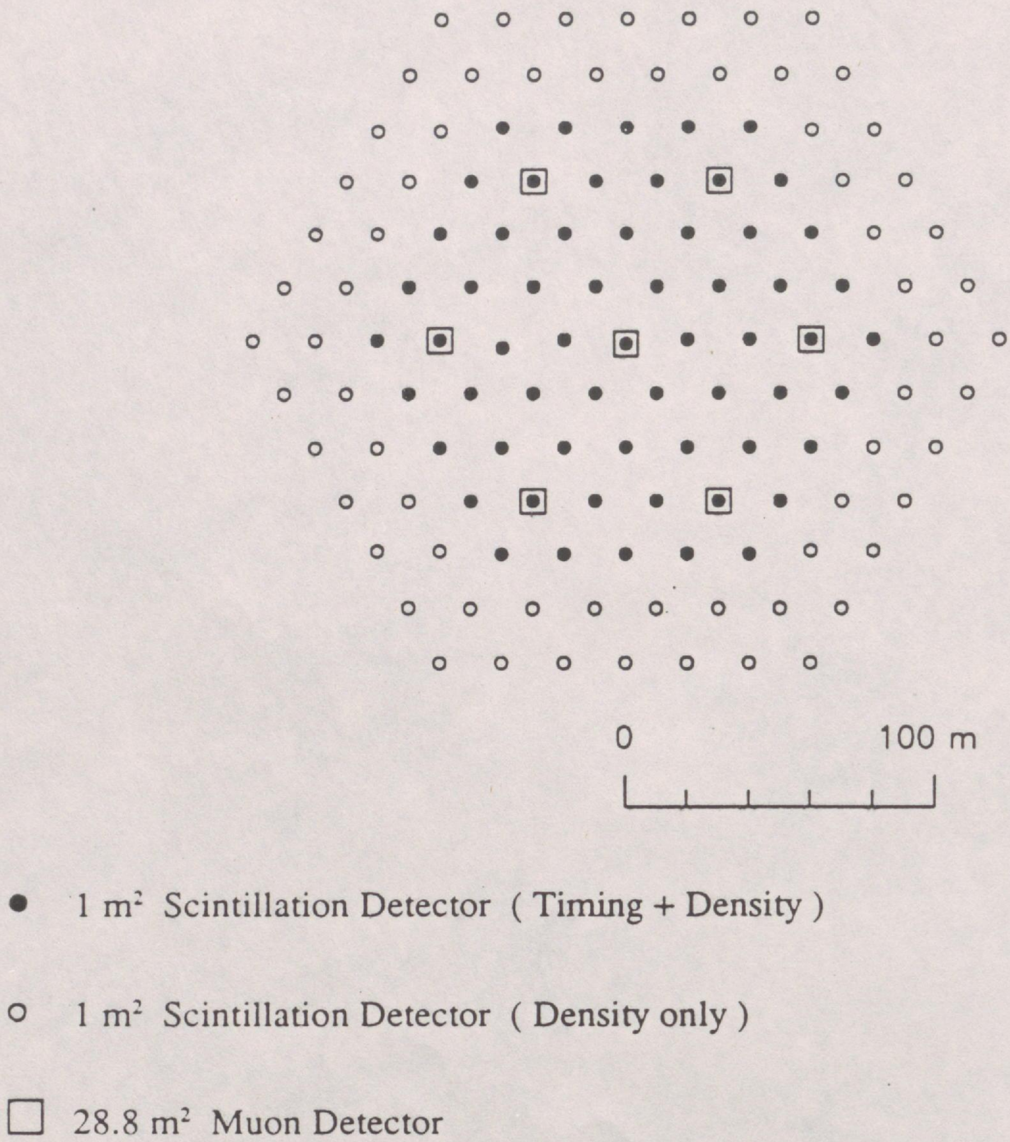

Fig. 2. A typical air shower array for PeV gamma ray observations being operated at Kolar Gold Fields (KGF), India. The total number of particles, called shower size, and hence the energy of the primary particle, are estimated from the number of shower particles recorded in the density detectors shown as open circles. The arrival direction of the shower is obtained from the relative arrival times of the shower front recorded in the timing detectors shown as filled circles. The 7 muon detectors, shown as squares, sample the muon component in the shower.

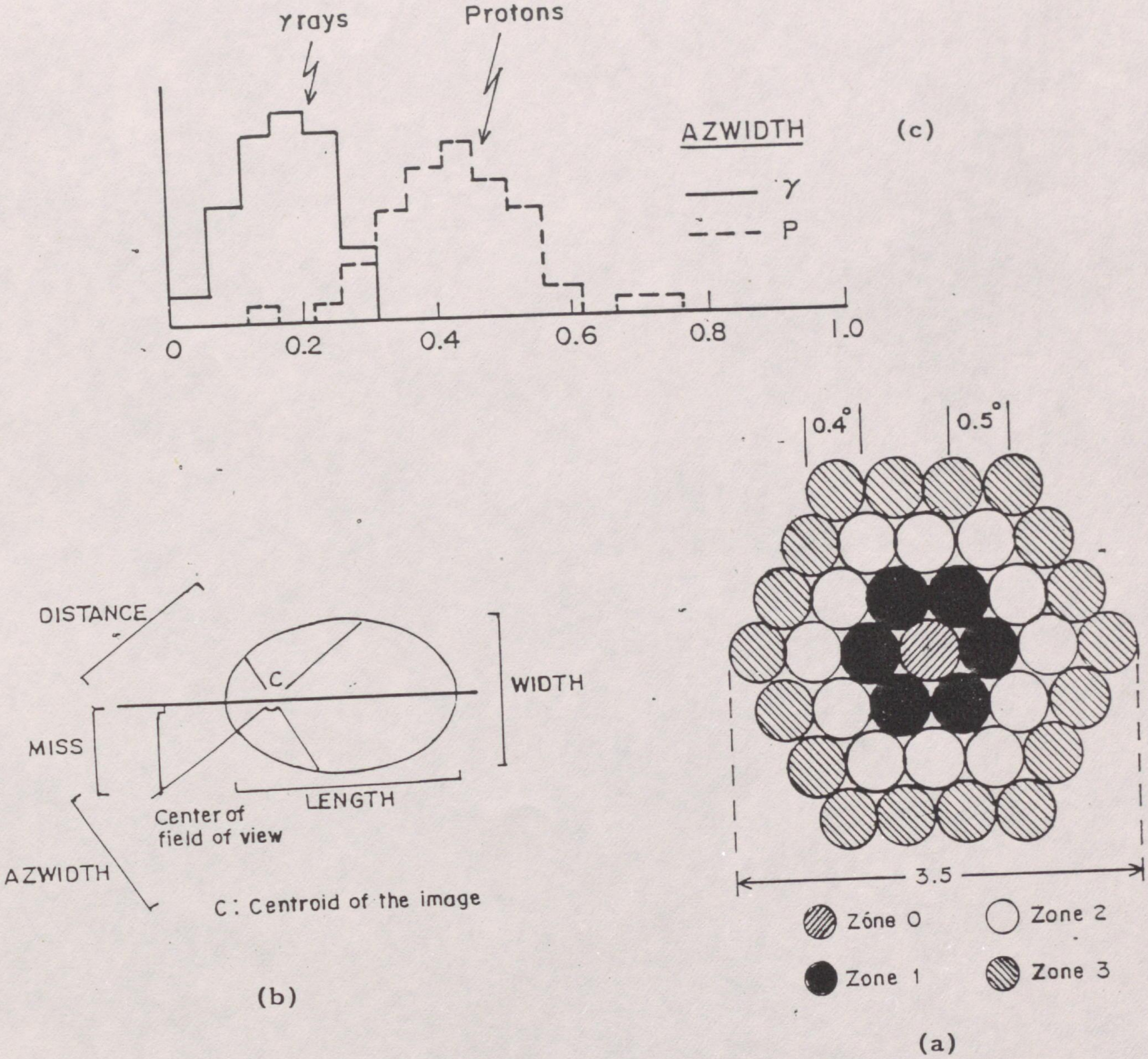

Fig.3. The figure illustrates the principle of operation of the Imaging Camera developed by the Whipple Observatory group. The assembly of 37 photomultipliers (a) each with an angular response of $\sim 4°$ records the image of the Cerenkov pool of light as an elipse. The parameter azwidth as defined in (b) is measured for each shower and those with azwidth < 0.2 are classified as photon induced showers; the justification for this classification can be seen from (c) which is obtained through Monte Carlo simulations for proton induced and γ-induced showers.

photon induced and hadron induced showers can be made making use of the muon content of the showers. In the case of photon induced showers the muon content should be almost a factor of ten less than in hadron induced showers. Let us now examine some typical results in these areas of Tev and Pev astronomies.

<u>The Crab Nebula:</u> (a Supernova remnant and a Pulsar)

The Crab Nebula is a hot web of expanding gas that can be seen with any medium size telescope; It is the remnant of a supernova explosion of a star in the constellation Taurus that happened on the 4th July 1054 A.D. The optical emission from the Nebula is highly polarized. It is a strong radio and X-ray source. In 1968 a radio pulsar of period 33 ms was detected in the centre of the nebula and later identified as the S.N. remnant star.

In the early 50's it had been suggested by Schklovsky that the Crab could be source of high energy cosmic rays. He interpreted the polarised optical radiation as due to synchroton emission by electrons gyrating in the magnetic fields of the filaments of the nebula and the same mechanism that accelerated electrons to energies of tens of Tev could also accelerate protons. Experiments using the Night Air Cerenkov Technique carried out by Soviet scientists could set only upper limits to the emission of Tev photons from the nebula. With the discovery of the Pulsar in the Crab Nebula it became clear that there could be many mechanisms which could accelerate charged particles to Tev energies in the environment of a spinning magnetic neutron star. New searches with improved experimental systems began for steady and pulsed Tev emission from the crab. While several experiments recorded episodic pulsed emission, there was no evidence at all for a steady unpulsed emission from the Nebula. The Imaging technique described earlier has however enabled the Whipple group to establish at a very high significance level (20 σ) that the Crab Nebula is a steady source of Tev gamma rays. What is intriguing however is that the Tev emission is not pulsed. The reported flux is $\sim 10^{11}$ photons/cm^2sc at E > 0.4 Tev. The emission is found to be constant in intensity over periods of several months. It is important to mention that there have been several reports of episodic Tev emission from the Crab Nebula and invariably in these case the emission is pulsed and the peak in the Tev domain coincides with either the main or the interpulse observed in the radio. Typical examples of pulsed emission recorded at Ooty and Pachmarhi by the TIFR groups[3] is shown in Fig. (4).

In the Pev region, for the first time there has been an interesting development. The Baxan Extensive Air Shower group[4] in the Soviet Union reported the observation of a Pev burst from the direction of the crab during 1400-1900 U.T. on February 23, 1989. This observation triggered the TIFR group[5] to examine the data from the KGF array. Indeed a burst was detected in the KGF data on the same day and the maximum shower intensity was during the time 13.25-16.00 U.T. The crab transit at KGF was at 14.1 UT earlier to the meredian transit at Baksan by 2.4 hrs. Confirmation of the burst lasting for several hours came from two other group - the EASTOP[6] at Gran Sasso and the Tien Shan[7] in the Soviet Union. The combined results

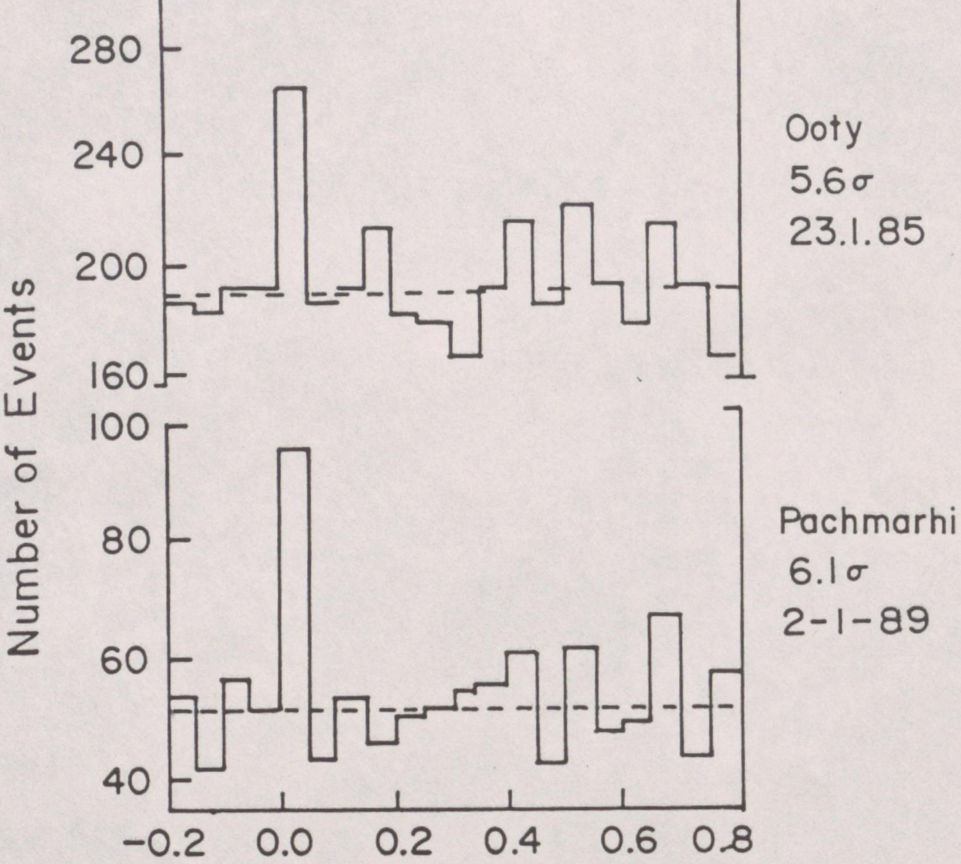

Fig.4. Tev Gamma Ray Bursts recorded by TIFR group at Ooty (23-1-85) and Pachmarhi (2-1-89)
The Ooty burst was seen by two telescopes separated by 9 kms
The Pachmarhi burst was seen by all five independent telescopes

of all the groups is shown in Fig. (5). The KGF data revealed two further aspects - that the emission is pulsed and also that the showers associated with the burst have the same number of muons as the normal hadron induced showers, a feature which we have seen is not characteristic of photon induced cascades unless the behaviour of photons changes at very high energies. Thus the muon association raises several important questions - Are the primaries of these showers neutrinos which interact with almost hadronic cross-section at these energies? or is the Crab emitting new type of hadrons that are long lived or do the photons behave like hadrons at very high energies? Further observations on similar bursts are necessary to clarify the situation.

Cyg X-3 (An accreting binary with a collapsed object)

Cyg X-3 entered the catalog of astronomical objects in 1966 as one of the brightest X-ray sources discovered with the first X-ray satellite UHURU, which also revealed it to be a binary system with a period of 4.79 hrs. Cyg X-3 was however found to be a very weak radio source. A chance observation by a Canadian astronomer on 2nd September 1972 showed that the intensity of the source in radio had shot up by a factor of a hundred. The bursting activity came down to normal after a few days. The source flared up again several times in the month of October. Since then Cyg X-3 is under continuous radio watch and it has been established that the source exhibits flaring activity atleast once a year. Because of this unique feature international efforts have been mounted to carry out simultaneous observation of the source in many bands of the electromagnetic spectrum during such

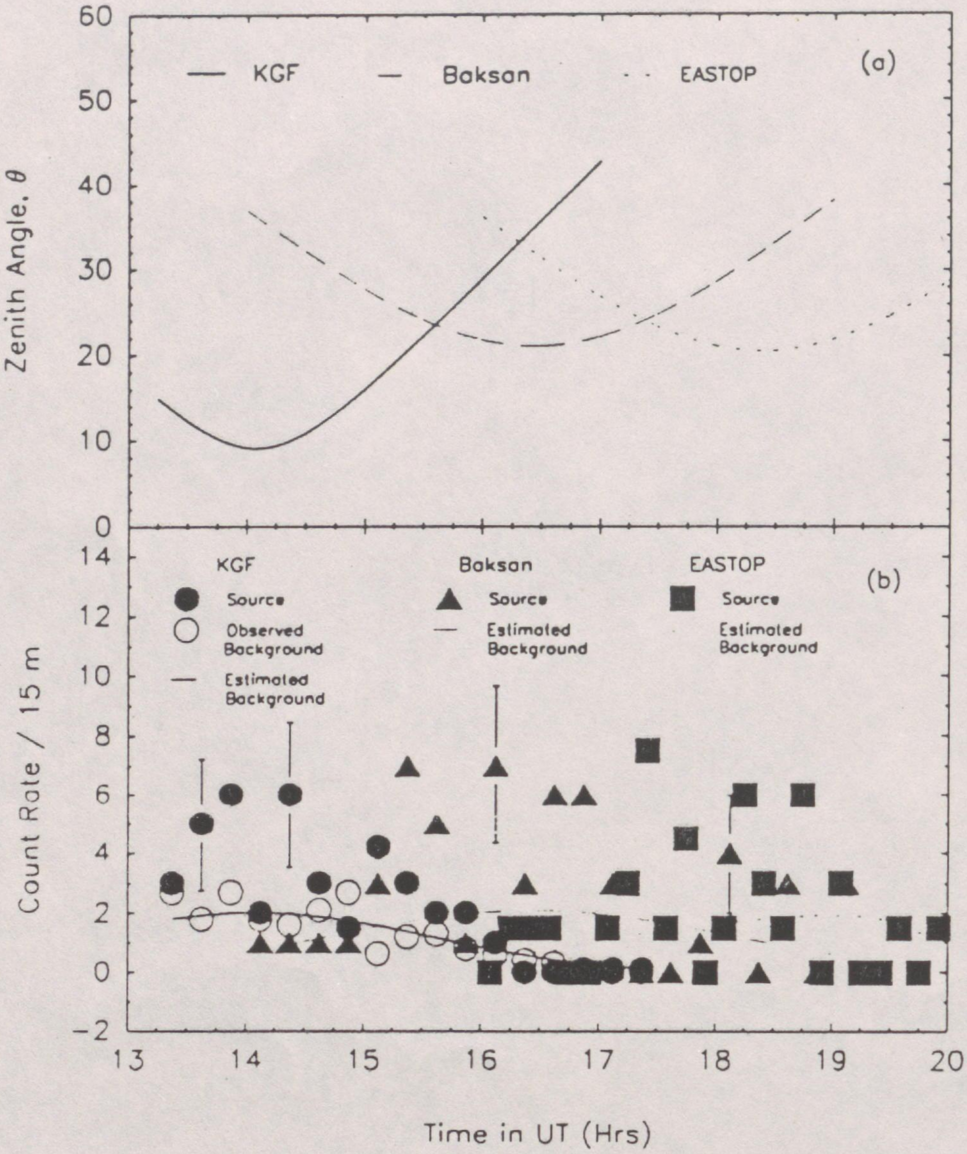

Fig.5. (a) Variation of the zenith angle of Crab with time on 23 February 1989 for the KGF, Baksan and EASTOP arrays.

(b) Counting rate in 15-min intervals of events arriving from the Crab direction, plotted against Universal Time for the KGF, Baksan and EASTOP data. The background rates of cosmic rays are estimated assuming an angular distribution of $\text{Cos}^7\theta$ and normalised to the total expected background over the respective periods. The open circles represent the background at KGF obtained from the data itself.

flare periods. The results of one such effort executed in 1985 is shown in the Fig.(6).

As early as 1972, the Crimean Astrophysical Observatory group[8] reported the observation of Tev gamma rays from Cyg X-3 with a period of 4.8 hrs. The observation was made during September-November of 1972, and radio bursts had occurred on September 2, 19 and 22. The occurrence of this kind of episodic emissions of Tev gamma rays from Cyg X-3 were later confirmed by many other groups. In 1983 at the International Cosmic Ray Conference held in Bangalore, the Kiel air shower group[9] in Germany reported the observation of a 5σ excess from the direction of Cyg X-3 based on the analysis of their extensive air shower data ($E > 10^{15}$ev) collected over a period of 3 years from 1976-79. Since then Cyg X-3 has been one of the objects studied extensively in the very high energy region of Tev and Pev astronomies. While some groups have confirmed the observations in the Pev domain like the Havarah Park Air Shower group[10] in U.K., the Akeno air shower group in Japan,[11] many have reported negative results.

A new feature that has been added to the already complex behaviour of Cyg X-3 is the occasional observation of a pulsar of 12.59 millisecond period in the Tev domain by the University of Durham group U.K.[12] If this is confirmed, then the collapsed object in Cyg X-3 will be a neutron star. An anomalous but very significant aspect of the Kiel result was that the showers from the direction of Cyg X-3 had roughly the same number of muons as in the normal hadron showers - an anomaly similar to the one that we

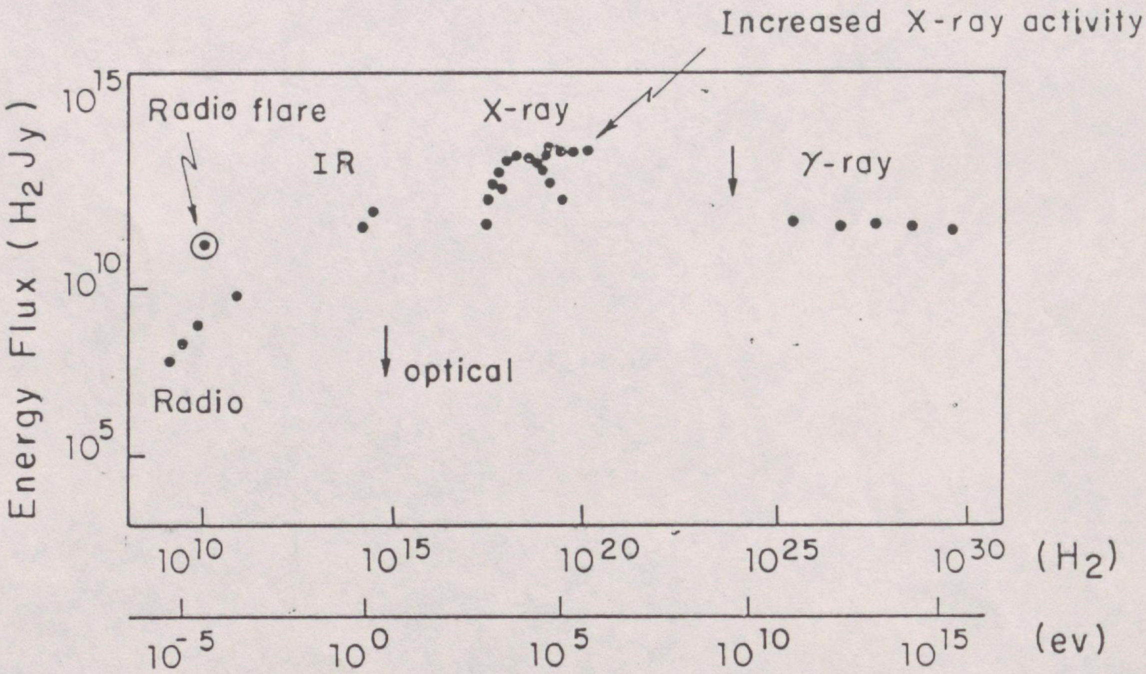

Fig.6. Simultaneous Observations on Cyg X-3 in different bands of the electromagnetic spectrum during October 1985.

Energy Flux is expressed in Hertz time Jansky

(1 Jansky = 10^{-26} Watt m^{-2} $hertz^{-1}$)

The Laboratories that participated in this simultaneous observations are:

(i) VLA in Mexico
(ii) Caltech Millimeter Wave Length Telescope
(iii) NASA 3-Meter IR Telescope on Mauna Kea, Hawaii
(iv) X-ray Monitor on EXOSAT
(v) Gamma Ray Observatory, Mt. Hopkins, Arizona
(vi) Gamma Ray Observatory at Halekala Crater, Hawaii
(vii) Gamma Ray Observatory at Haverah Park, U.K.

have discussed earlier in the case of Crab. The muon anomaly is heightened by the observation of the Soudan group[13] in USA of muons of energy greater than 0.7 Tev in their Proton Decay detector at a depth of 2090 m.w.e. from the direction of Cyg X-3. The observations were made during 82-83. A similar observation of muons of energy > 5 Tev was also reported by the Italian Proton Decay group[14] NUSEX, operating in the Mont Blanc Tunnel. Some of the other groups have negative results from their underground muon detectors. The statistical significance of these however is not sufficient to nullify the positive results. Further the Soudan group[15] reported the observation of a short duration burst of muons (> 0.7 Tev) from September 18 to October 18 from Cyg X-3 during the radio flare period of October 85. The muons appear to precede the radio signal by one week. The muons arrived in a narrow phase range 0.725-0.745 in the binary period. Very recently there have been further reports of muon burst emitted during the radio flare period of 19th to 25th January 1991. While the Soudan group has seen excess of muons on the 20th and 23rd January, the KGF group[16] reported excess on 18th and 19th January. The muons seen by the KGF group have energies > 8 Tev. The results of the Soudan group is shown in Fig.7. Though these are rare events they have a high statistical significance. Clearly such investigations need to be follwed up for several years before a clear picture can emerge, especially since Cyg X-3 does not appear to be a steady source at these energies, but flares up only occasionally, with long periods of quiesence.

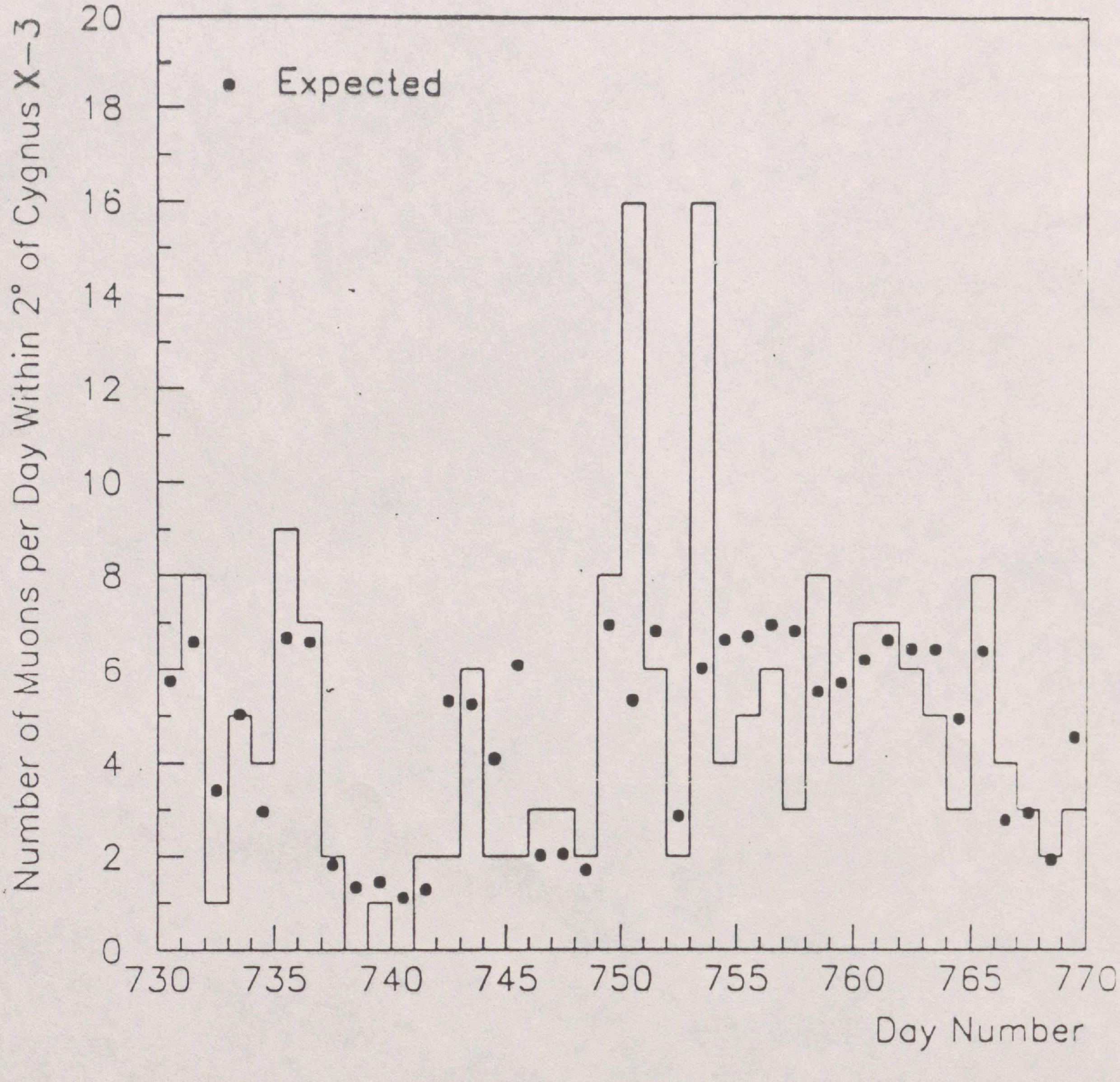

Figure 7. The number of muons detected within a 2.0° half-angle cone centred on Cygnus X-3 versus calendar day number. Days 750 and 753 are 20th and 23rd January 1991 (CST) respectively. The superimposed points are the expected numbers of muons. The expected number depends upon the livetime of the detector on that day. The error on the background estimate is $\sim$ 13%.

Active Galactic Nuclei (Accreting Super Massive Black Holes)

The quasars, the Seyfert galaxies, the BL Lacerta, the Catacysmic Variables which have been classified as AGN's have been known to be extremely powerful sources in the radio, optical X-ray and γ-ray domains. The notion that these active galactic nuclei are powered by accretion of matter on to super massive ($10^6 M_\odot \sim 10^9 M_\odot$) black holes is gaining ground. The required mass accretion rate is about a Solar Mass per year. It is interesting that in the case of NGC 4151 an X-ray flare event that lasted for less than an hour has been registered, indicating that the X-ray emitting region is indeed small $\sim 10^{15}$ cms, thus supporting the hypothesis of the presence of giant black holes at the centres of such objects.

The scenario of a giant black hole at the centre of an AGN with a rotating accretion disc has important consequencies for very high energy astronomies. In such a scenario an accretion shock is formed due to in fall of matter and gravitational energy is converted into highly relativistic particles which in turn could lead to the production of very high energy neutrinos. This aspect has been particularly emphasised by the Soviet scientists for more than a decade. Stecker and his collaborators[17] have recently evaluated the flux of very high energy neutrinos 10^{14} - 10^{20}ev that could be generated following the interaction of the relativistic particles with the ambient X-ray and ultra violet photons in the immediate vicinity of the AGN. They have used the recent satellite measurements of X-ray and ultra violet photons in evaluating this flux of neutrinos. What is most surprising is that the integrated flux of neutrinos in the energy range 10^{14} - 10^{20}ev from all the AGN's is fairly high (Fig.8) and falls well within the capability of measurement with some of the existing detectors like the IMB proton decay detector, the MACRO installation in the grand Sasso tunnel and the DUMAND deep ocean detector in Hawai. For the first time the prospects of very high energy neutrino astronomy has opened up and it is hoped that with newer technologies and larger installations it may become feasible even to record the neutrino fluxes from individual AGN's.

A new and novel type of detector system AMANDA has been planned by the US groups[18] for neutrino astronomy. In this it is proposed to use several kilometers thick ice layer in the Antartic as the target material for neutrino interactions as well as for the generation of cerenkov radiation by the charged secondaries produced in the neutrino interactions. The ice at depth of more than a kilometer is expected to be bubble free and highly transparent. A series of photomultipliers lowered to different depths in specially made bore holes in the the ice are proposed to be used for detection of the cerenkov light.

Conclusion

Very High Energy Gamma ray and particle astronomies have come of age. The Crab Nebula has been established beyond doubt as a source of Tev gamma rays. In the Pev domain, while no steady emission from any source has yet been established episodic emissions mostly pulsed in nature have been seen from several sources including Crab. The enigmatic X-ray binary Cyg X-3 has turned out to be quite an interesting object in very high energy

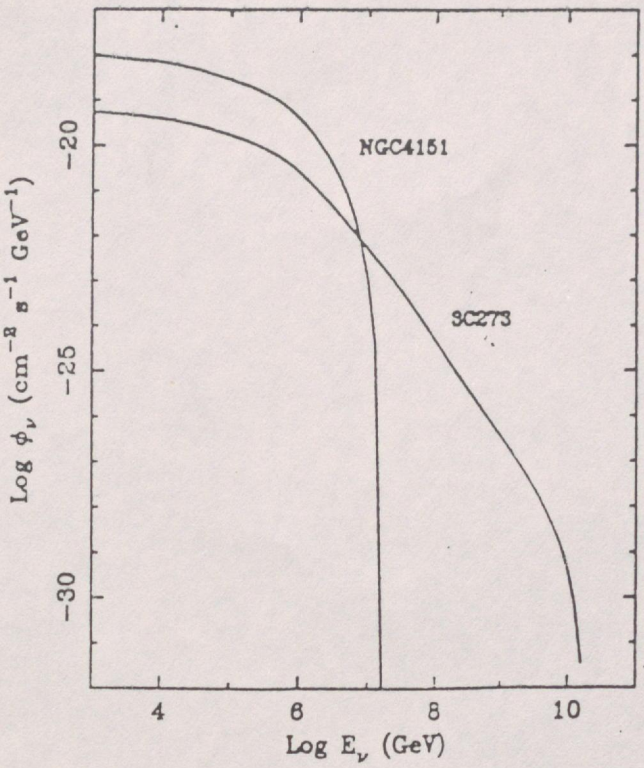

Fig. 8(a)

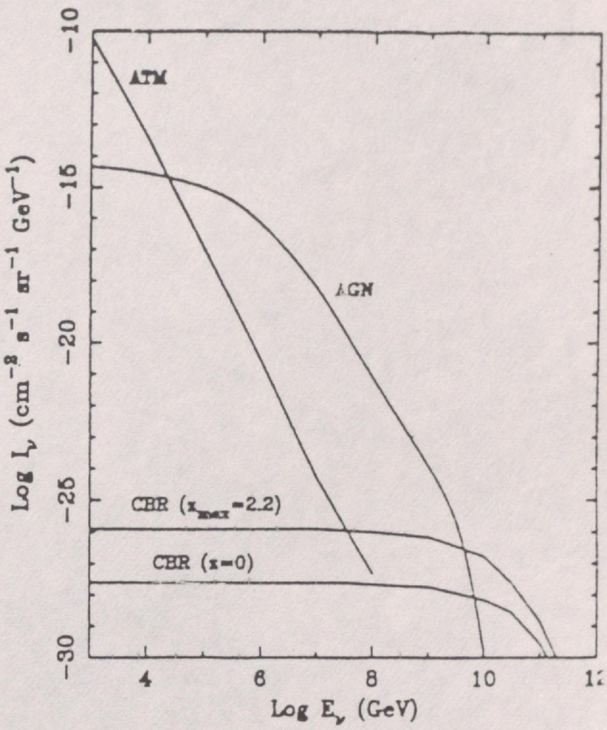

Fig. 8(b)

Fig. 8(a) : The predicted ν_μ ($\bar{\nu}_\mu$) flux from NGC4151 which has an X-ray luminosity of $L_x = 3 \times 10^{41}$ $ergs^{-1}$ and is at a distance of 4.5×10^{25}cm and From 3C273 with $L_x = 10^{47} ergs^{-1}$ and distance 3×10^{27}cm. The ν_e and $\bar{\nu}_e$ flux is half that of ν_μ ($\bar{\nu}_\mu$).

Fig. 8(b) : The integrated high energy ν_μ ($\bar{\nu}_\mu$) neutrino background from AGN. Also shown is the horizontal ν_μ ($\bar{\nu}_\mu$) flux from high energy neutrinos from cosmic rays interacting in the earth's atmosphere (ATM) and the background expected from photomeson production of extragalactic high energy cosmic rays with cosmic background radiation (CBR).

astronomies too. There have been claims and counter claims of episodic emissions from this source in both Tev and Pev domains and also as a bursting source in Tev muons, associated with radio flaring activity. The active galactic nuclei which possibly have super massive black holes in their centres hold promise of the realisation of very high energy (10^{14} - 10^{20}ev) neutrino astronomy. With these developments ~~it looks that~~ the century old problem of the sources of cosmic radiation seems to be nearer to a solution.

BVS/ysa.
19911204

R E F E R E N C E S

1. Acharya, B.S. et al Cosmic Gamma Rays, Neutrinos and related Astrophysics (Kluwer Acad. Publishers Ed. Shapiro, M and Wefel, J.P.), (1989), 235.

2. Weekes, T.C. Phys. Report **160** (1988) 1

3. Gupta, S.K. et al Ap.J. **221** (1978), 268
Viswanath, P.R. (Private Communication).

4. Alexeenko, V.V. et al (Proc. Int. Workshop on Very High Energy Gamma Ray Astronomy, Ed. Fegan, D.J. and Cowley, M.F.) (1989), 187.

5. Acharya, B.S. et al Nature **347** (1990), 364.

6. Aglietta, et al Europhys. Lett. **15** (1991), 15.

7. Chudakov, A.E. (A I P Conference Proceedings High Energy Gamma Ray Astronomy, Ann Arbor, Ed. James Mathews), (1990), 132.

8. Vladimirsky, B.M. et al Proc. 13 ICRC, Denver **1**, (1973) 456.

9. Samorski, M. and Stamm Ap.J. **268** (1983) L17.

10. Lloyd Evans, J. et al Proc. 18th ICRÇ Bangalore **9**, (1983), 65

11. Kifune, T. et al Ap.J. **301** (1986) 230.

12. Chadwick, P.M. et al (Proc. NATO Workshop on Very High Energy Gamma Ray Astronomy), (1986), 115.

13. Marshak, M.L. et al Phy. Rev. Lett. **54** (1985), 2079
Phy. Rev. Lett. **55** (1985), 1965

14. Battistoni, G. et al Phys. Lett. B (1986), 465.

15. Thomson, M.A. et al Preprint No.OUNP 91-17, ANL-HEP-PR 91-75 (1991)

16. Adarkar, H.R. et al (Private Communication).

17. Stecker, F.W. et al Phy. Rev. Lett. **66** (1991), 2697.

18. Barwick, S.W. et al (22nd ICRC, Dublin Conference Abstracts 2, (1991), 935.