

HIGH ENERGY ASTRONOMIES - NEW WINDOWS ON THE UNIVERSE

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First of all I would like to thank the Andhra Academy of Sciences for having invited me to participate in this seminar on "Advances in Space Sciences" which has been organised as part of the Silver Jubilee Celebrations of the Academy. I would like to congratulate the academy on the completion of 25 glorious years characterized by high level academic activity.

Astronomy is an old science - perhaps the oldest of all sciences and began with naked eye observations of the sky, followed in the last few hundred years by observations with larger and larger telescopes. In my talk to-day I want to highlight the transformation that has taken place in the field of astronomy with the advent of Space Technology which itself is a product of the tremendous advances in chemical, material aeronautical and ofcourse electronic technologies.

Information concerning the multitude of objects that populate the vast stretches of Space and of the interstellar medium itself, is coming to us in a variety of forms : Electromagnetic Radiations - Radio, Infrared, Optical, Ultraviolet, X-ray, Gamma Rays and Very High Energy Gamma Rays; Charged Particles - Cosmic Rays - Protons, - Alpha Particles, Heavy Nuclei; Neutrinos; Gravitational Waves and Possibly Exotic Particles - Monopoles, Axions, Quark Nuggets, Cosmons, some of which could have been produced in the very early universe - immediately after its birth.

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The physical processes responsible for these radiations are thought to be : molecular and atomic excitations - free free transitions, bremsstrahlung; synchrotron radiation, nuclear collisions producing pions, kaons, nucleons, anti-nucleons. The decay of pions and kaons give rise to muons, neutrinos and gamma rays. The frequency of occurrences of these processes depend on the stellar environments - temperature, density, energy of the individual particles, strength of electric and magnetic fields, etc.. Low energy neutrinos are produced copiously in the thermo-nuclear processes in the core regions of the stars like the Sun and also in the gravitational collapses of the remnants of the exploding stars (the Super Novae). Electron capture during gravitational collapse leads to the production of neutrinos in the tens of Mev energy region. In addition the universe is also filled with the relics from the Big Bang - the radiations and particles produced in the very early phases of the universe - the high energy photons which have now degraded to millimeter wave photons (black body temperature of  $2.7^{\circ}\text{K}$ ) and the Cosmological neutrinos ( $\sim 1.9^{\circ}\text{K}$ ). Gravitational waves are produced when stars collapse and also due to the fast rotation of collapsed objects.

In some of the very special celestial environments characterized by high magnetic fields and electric fields as in the case of fast spinning magnetized neutron stars, charged particles get accelerated to very high energies. These leak out and form the Cosmic rays encountered in the galaxy and also incident on the earth. If the neutron star is part of a binary system then the high energy particles produced collide with the material of the companion star and give rise to high energy charged and neutral pions. The neutral pions decay into  $\gamma$ -rays which travel to the earth from the source without being deflected by the galactic magnetic fields unlike their charged counterparts. Thus from the point of view of identifying the sources of Cosmic rays there is considerable interest in detecting gamma rays from such objects.

The techniques that have been used for the detection of these different radiations are also naturally very different. For the Optical, Infrared and Ultraviolet radiations conventional focussing mirrors of varying diameters have been employed with focal plane instruments like photographic plates, photomultipliers, and in recent times CCD's and solid state devices. Large Antenna Systems Parabolic, and Cylindrical Parabolic with focal plane dipoles designed for specific wave lengths characterise radio telescopes, which with the advent of modern electronics and computers have achieved tremendous capabilities in terms of resolution and imaging capabilities and in recording signals from very very distant sources, from almost the edge of the universe. The X-ray and Gamma ray telescopes have an entirely different structure and design. Standard techniques cannot be used. Special types of Grazing incidence focussing systems have been used in the soft X-ray region, and for higher energy X-rays and Gamma rays the modulation collimators and the technique of Coded Masks have been employed successfully. The detectors range from proportional counters to gas scintillation counters and phoswich assemblies of Sodium Iodide and Caesium Iodide. While the observations in the Radio and Optical regions and in a few limited infrared bands can be made from the ground, observations in the shorter wave lengths of ultraviolet, X-ray and gamma rays can only be made from above the earth's atmosphere, since these radiations are very severely attenuated by the atmosphere. The developments in Space technologies - Stratospheric balloons, rockets and satellites have made possible detailed observations in practically all the bands of the electromagnetic spectrum.

At very high energies again in the Tev ( $10^{12}$  ev) and Pev ( $10^{15}$  ev) regions, observations from the ground become feasible. Gamma rays at energies greater than a few Tev lead to the development of sizeable electromagnetic cascades in the atmosphere. The electrons produced in these cascades give rise to cerenkov radiation in the optical and

ultraviolet bands, which travel right down to the ground level, without much attenuation. These radiations which retain the original direction of the gamma rays are then collected by suitably oriented search light mirrors and focussed on to photomultipliers at their foci.

Fast electronic coincidences between arrays of parallelly oriented mirror systems enable the detection of the gamma rays. The system of mirrors are electrically controlled to track any suspected source (Fig. 1 ). The only limitation of this technique which is known as the night air cerenkov technique is that it can be employed only on clear moonless, cloudless nights.

For the detection of the still higher energy Cosmic ray charged particles, the method of extensive air showers is employed. A primary of say  $10^{15}$  ev collides with an air nucleus and produces a large number of charged and neutral pions, kaons and also nucleons and antinucleons. These particles travel further down and again collide with air nuclei and give rise to second and subsequent generations of similar particles. This is known as the nuclear cascade. The short lived mesons however decay immediately into a pairs of gamma rays which in turn give rise to electromagnetic cascades. Thus the nuclear cascade feeds into the electromagnetic cascade lot of energy. Some of the charged pions and kaons decay into muons and neutrinos, which form the penetrating particles that are observed in deep underground laboratories. An array of scintillation counters enables the detection of charged particles. The arrival direction of the shower is determined by measuring the delay between the different scintillation counters to an accuracy of a few degrees. The muons and neutrinos are detected by large assemblies of proportional counters or water cerenkov tanks or large liquid scintillation counter systems in deep underground laboratories.

What have we learnt from all these observations about the Universe ? The Fig.(2) illustrate the enormous range of masses, and sizes of the different constituents of the Universe - from nuclei to planets to stars to galaxies to clusters of galaxies to the entire universe. The lowest mass is that of the nucleon  $\sim 10^{-24}$  gms and



Fig. 1 Typical array of Search Light Mirrors  
on individual electronically controlled  
orientation platforms for observation  
of Tev gamma rays.

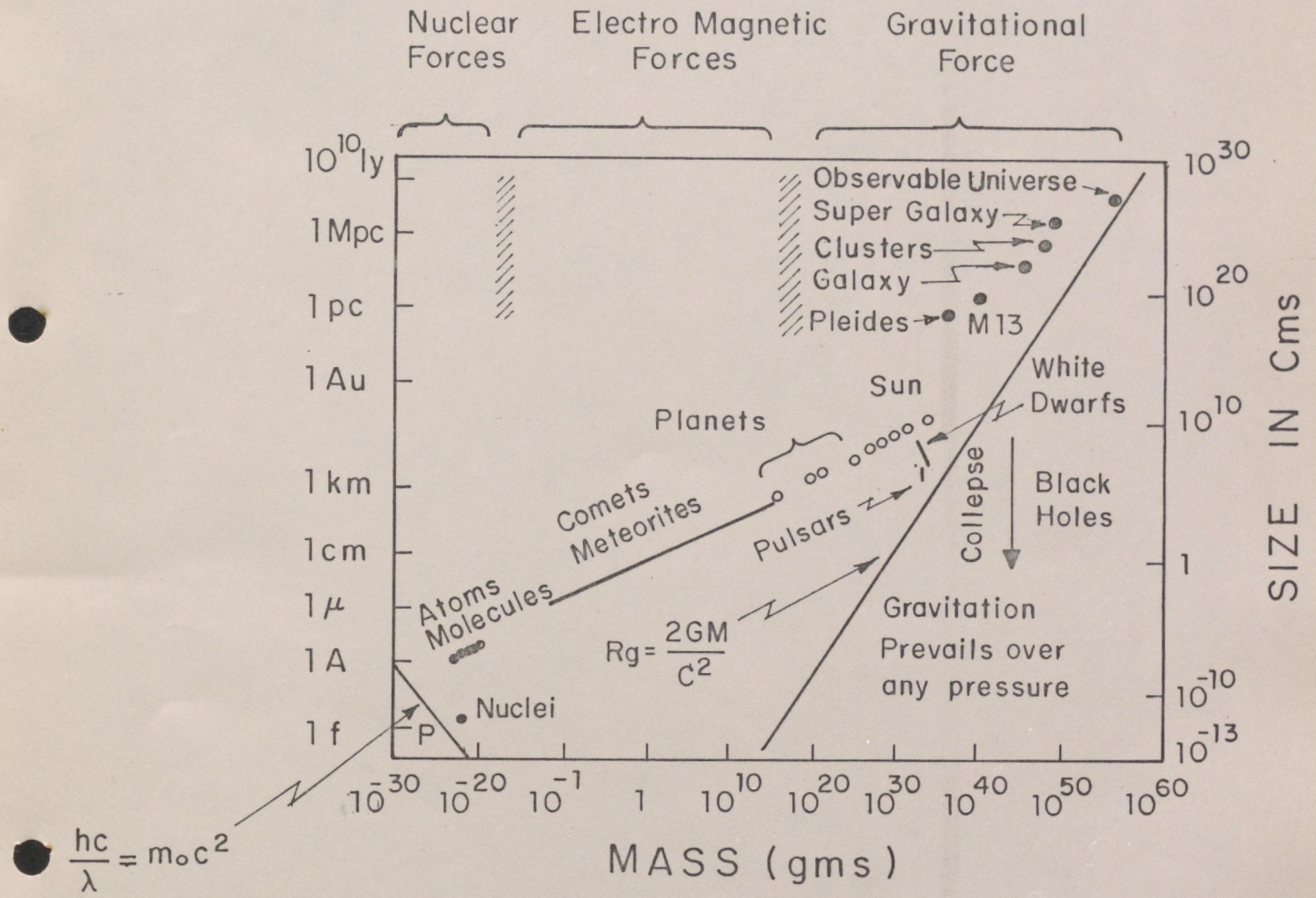


Fig.2. The Mass Vs Size of the different constituents of the universe. The objects which are of current interest in astronomy are those which are close to the line  $R_g = \frac{2GM}{c^2}$  (Pulsars) and below that line (Black Holes). The range over which different forces operate is also indicated at the top.

on the other side of the scale the total estimated mass of the universe is about  $10^{56}$  gms! The corresponding size scale extends from  $10^{-13}$  cms to  $10^{30}$  cms.

The universe is not only filled with the material objects, but also with radiation. The Fig.(3) shows the relative intensities in the different bands in a typical location far away from any bright source. The most dominant radiation on a universal scale is the Relic  $3^\circ$  Microwave radiation discovered in the early 60's. In addition some subtler features of the universe lead to the conclusion that it is also filled with an unknown amount of other particles and radiations like neutrinos, gravitons, and may be exotic particles like Photinos, Sneutrinos, Axions, etc.. A surprising feature is that within the frame work of the current ideas of its creation, expansion, density, etc. it is almost a certainty that 90 to 99% of the matter in the universe is in a form whose nature and identity still needs to be established.

Different aspects of astronomical information have received special attention of physicists and astrophysicists at different times in the past. In the last couple of decades however with the discovery of pulsars, X-ray and Gamma ray sources, X-ray and gamma ray bursts, their interest is focussed on gravitationally collapsed objects. These are characterised by environments of extremely high dense matter, high magnetic fields, high electric fields, high angular momentum states, etc. and provide the kind of astronomical sites where several types of high energy phenomena can take place. It is impossible to produce such extreme physical conditions in the terrestrial laboratories. While the individual collapsed objects by themselves are of interest, those which are part of close binary systems and accrete matter on to themselves have become particularly interesting. These provide a variety of special scenarios in the high energy domain and have made the field of High Energy Astronomies distinctly different and most fascinating. I shall try to give you a flavour of modern astronomical research - the multiple window approach - by describing in some detail a few typical cases of great current interest.

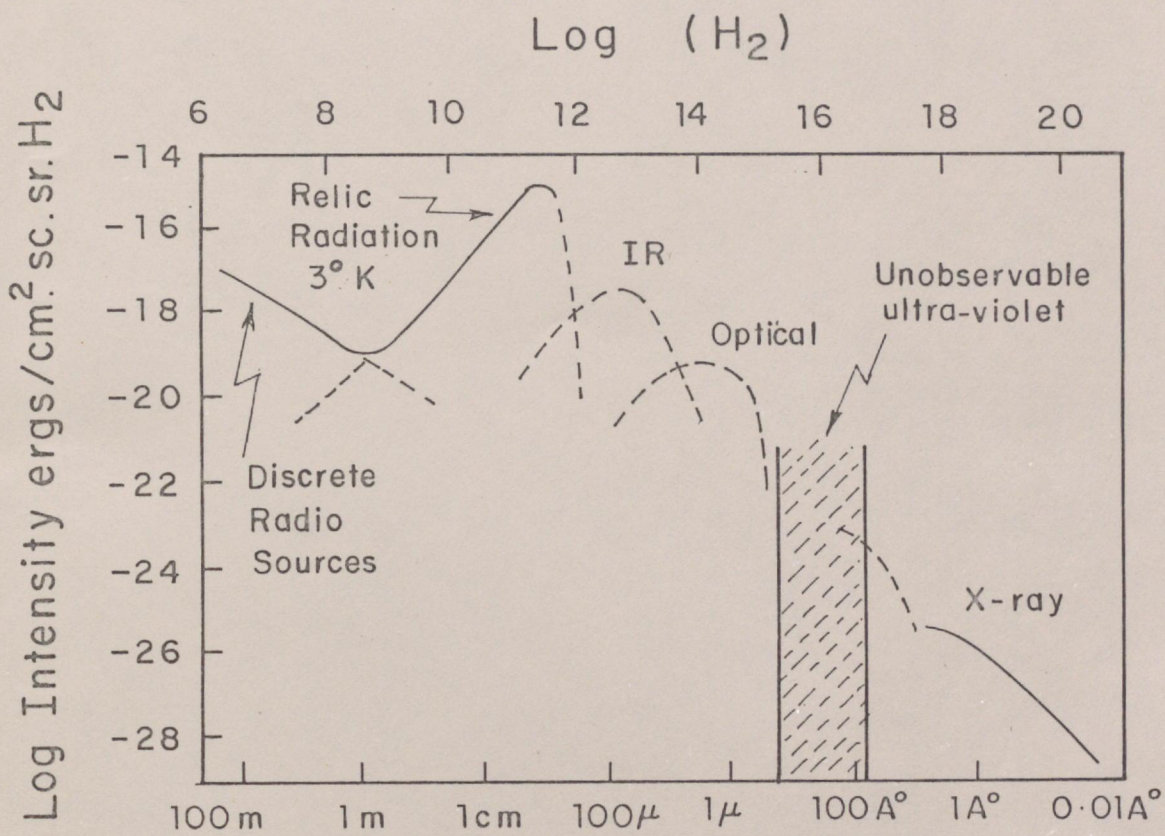


Fig.3. The Spectrum of the Isotropic Background Radiation in the Universe.

Full Lines - Observation  
 Dashed Lines - Theoretical Estimates.

Super Nova 1987a (SN 1987a)

Perhaps the most exciting astronomical event of 1987 was the observation of the explosion of a star in our neighbouring galaxy - the Large Magellanic Cloud (LMC). On the 23rd of February 1987; a Canadian astronomer, Ian Shelton, was taking long exposure of the LMC with a 10" telescope at the Las Campanas Observatory at Chile; the exposure continued till 2.40 a.m. on the 24th; instead of going to sleep after a hard day's work, Shelton chose to develop the photographic plate the same night; What a lucky decision! Lifting the plate from the developing tank, he was amazed to find a bright spot in the region of the Tarantula Nebula; The star was too bright to have been missed in earlier observations if it was there all along; He went out into the open and looked in the direction of LMC and Lo and behold, he could see with naked eyes the bright star - what he had seen was the brightening of the star due to its explosion. He had sighted the Super Nova 1987a.

The previous occasion when a man had sighted the explosion of a star in the sky was 383 years earlier and that man was none other than the famous astronomer, Kepler. We do not know how much of excitement was there at the time of Kepler. But the sequence of events after Ian Shelton's observation illustrates the excitement and concern of astronomers that this event has caused all over the world.

The Table shows the sequence of events that preceded and followed the observation by Ian Shelton.

What is most exciting and pleasing to scientists working in this area of astrophysical research is that the underground installations in Japan and in the United States registered the arrival of "neutrinos" full 18 hours before the optical sighting was done consistent with theoretical predictions of the various types of phenomena that should precede and follow such stellar explosion. There is even an indication of another neutrino burst in the data from the Mont Blanc underground

TABLE

Sequence of Events before and after SN1987a

Feb. 23, 1987

|                  |   |
|------------------|---|
| 1.25 - 2.25 (UT) | Ian Shelton photographs LMC.<br>Nothing unusual   |
| 2.5 - 2.37       | Neutrino Detectors in Mont Blanc<br>pick up burst of five neutrinos<br>(questionable according to some)<br>Gravitational Waves picked up in Italy and USA ? |
| 7.3 5.41         | Proton Decay Detectors of IMB in USA and<br>Kamiokande in Japan pick up<br>Neutrinos Signals - 19 in all.   |
| 9.22             | Jones in New Zealand checks LMC.<br>Nothing brighter than 7.5 magnitudes.   |
| 10.38            | McNaught in Australia photographs LMC.<br>He does not develop the plate immediately.<br>The star was already 6 Mag. (Misses Discovery!)                     |

Feb. 24, 1987

|                  |   |
|------------------|---|
| 1.30 - 4.30 (UT) | Ian Shelton's observation in Chile<br>Mag 5. <u>Discovery of SN 1987a.</u> *<br>Naked Eye observation by Duhalde. |
| 8.50             | Jones in New Zealand independently<br>discovered SN 1987a - (too late!)   |
| 10.55            | McNaught records Mag. 4.8   |
| 19.00            | Astronomers in South Africa record<br>Spectrum of SN 1987a.<br>IUE obtains first Ultraviolet records.             |

Feb. 25, 1988

|       |  |
|-------|--|
| 10.00 | Radio Waves picked up by Fleurs Observatory<br>in Australia. |
|-------|--|

July 4, 1988

GINGA picks up X-rays (10.30 Kev).

August 1988

SMM reveals <sup>56</sup>Co 843 Kev line.

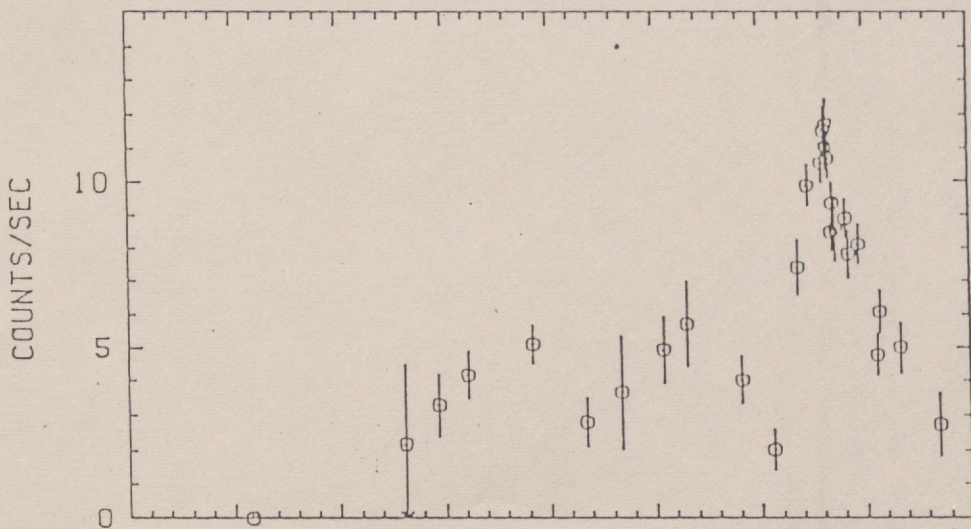
neutrino observatory with also a suggestion that gravitational waves may also have been recorded. The neutrinos and the gravitational waves reach earlier since they are not subject to scattering in the material surrounding the explosion region.

Since that eventful night of February 23rd 1987, the LMC region is under almost continuous monitor in many bands of the electromagnetic spectrum and also for particle emissions. A lot of valuable information has been gathered in the optical band - light curve, the expanding shell structure, the spectral features, etc.. The Japanese X-ray Satellite Ginga which was launched on February 5th 1987 started looking at SN 1987a for hard X-ray emission right from February 25, 1987. However the first clear signals in X-rays were seen only after July 4th 1987. Observations have been made in two energy bands 5.8 - 16.1 Kev and 16.1 - 27.8 Kev. (Fig.4) The X-ray intensity fluctuates by a factor of 2 to 3 and also exhibits a kind of burst activity around December-January period. The gamma ray Spectrometer on the SMM (Solar Maximum Mission) revealed evidence from  $\gamma$ -ray line emission at  $843 \pm 5$  Kev which is attributable to  $^{56}\text{Co}$  and is a vindication of the theories of nucleosynthesis of elements following Supernova explosions. The first appearance of the  $\gamma$ -ray line coincided with the detection of hard X-rays. A search has been made for still higher energy gamma rays 50 - 500 Mev, with an optical spark chamber flown on a balloon from Australia. The results have been negative. A search has also been made from high energy neutrinos ( $E_{\nu} > 600$  Mev) in the KGF Proton Decay Detector, with negative results so far. The search in very high energy gamma ray region ( $> 10^{14}$  ev) by the method of extensive air showers with the Buckland Park array in Adelaide and the JANZOS array in New Zealand have also proved negative so far. These positive and negative results in the various energy bands are important for understanding the evolution of the compact object and of the surrounding envelope as a function of time after the explosion.

### Cyg X-3

Let me now talk about another very interesting object in the sky, Cyg X-3, which is attracting the attention of astronomers working in the

SN1987A X-RAY LIGHT CURVE : 5.8 - 16.1 KEV



SN1987A X-RAY LIGHT CURVE : 16.1 - 27.8 KEV

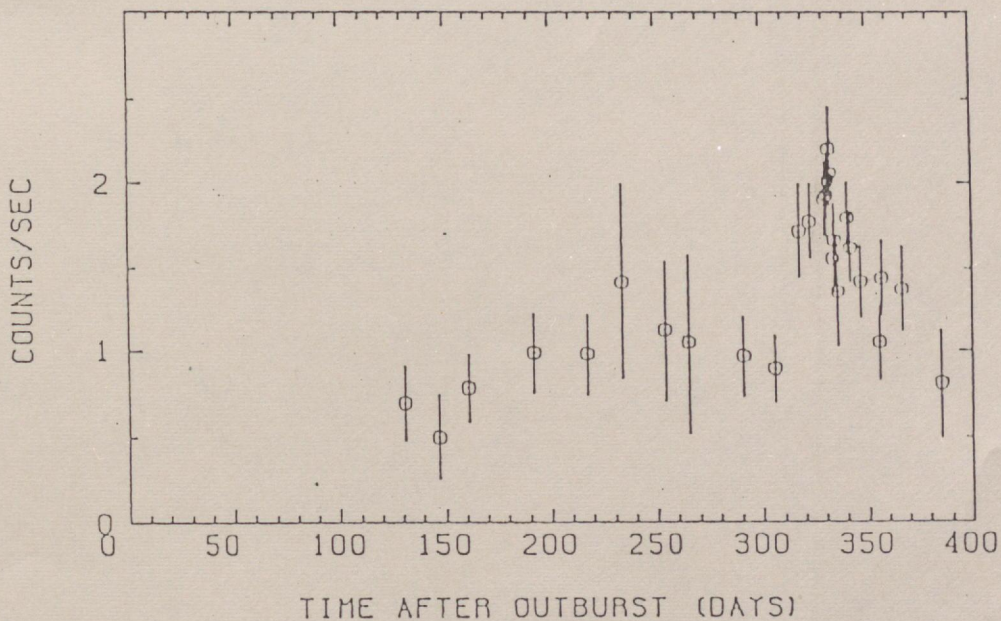


Fig.4, Hard X-ray observations by the Japanese Satellite Ginga on SN 1987a. There is evidence of an X-ray burst activity in December 87-January 88 period.

different bands of the electromagnetic spectrum and also particle physicists and high energy Cosmic ray physicists. Cyg X-3 entered the catalogue of astronomical objects in 1966 as one of the brightest X-ray sources discovered in that decade. The UHURU and Copernicus Satellites revealed 4.79 hour periodicity in X-rays and Cyg X-3 was naturally interpreted as a binary system with the X-ray source going round its companion every 4.8 hours. However, no pulsation was recorded from this source. Radio observations revealed it to be a very weak Radio Source. On the September 2nd 1972 something strange happened. A Canadian astronomer noticed by sheer chance, that the radio intensity from this source had increased by a factor of almost hundred, which declined after about 10 days. Since then Cyg X-3 has been found to flare up annually in the radio band and for some inexplicable reason mostly during the September-October period. Infrared radiation in the  $1.6\mu$  and  $2.2\mu$  bands also reveal the 4.8 hours periodicity. Optically however the object has not been seen presumably because it is located beyond a dusty spiral arm. In the gamma ray region the SAS II and COSB Satellites have given conflicting results. While SAS II has reported 4.8 hours periodicity in Mev gamma rays, COSB has not seen any flux. The most interesting observations have been in the very high energy range which we shall discuss in more detail later. There are conflicting results about the observation of Mu Mesons in the underground laboratories.

The importance given to the study of this source can be seen from Fig.(5) in which the results of multi spectral observations extending from Radio to very high energy gamma rays  $10^{10}$  Hz to  $10^{30}$  Hz are summarised. These observations were made in October 1985 when anticipating a radio flare in Cyg X-3, a world wide simultaneous observation in the different bands had been organised.

Using the night air cerenkov technique, Cyg X-3 has been examined by a number of groups in the Tev ( $10^{12}$  ev) region. The first to find 4.8 hours periodicity in this energy band is the Soviet group working in the Crimean Observatory. While many other groups have reported positive flux subsequently in the Tev energy range, there is

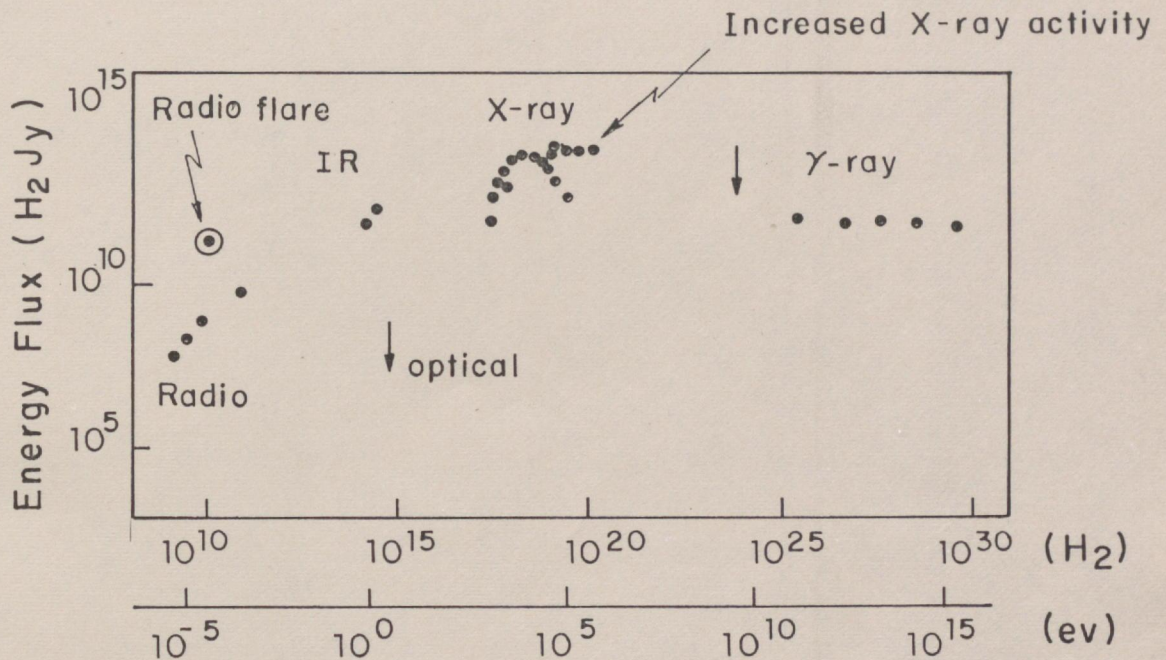


Fig.5. Simultaneous Observations on Cyg X-3 in different bands of the electromagnetic spectrum during October 1985.

Energy Flux is expressed in Hertz time Jansky  
 (1 Jansky =  $10^{-26}$  Watt m<sup>-2</sup> hertz<sup>-1</sup>)

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.

discrepancy about the phase in the 4.8 hours periodicity at which the signal is seen. It appears that emission takes place sometimes in the 0.2 phase and sometimes in the 0.6 phase, and may be sometimes in both these phases. Cyg X-3 created further interest in 1985 when the Kiel group from Germany reported at the International Conference on Cosmic Rays held in Bangalore, evidence for the emission of very high energy  $10^{15}$  ev extensive air showers from this direction with the signal getting enhanced when analysed in terms of the 4.8 hours period. Since then many Cosmic ray groups in the world have been searching for Pev showers. It looks that the source becomes active occasionally.

A very intriguing feature of the observation of the Kiel group was that the air showers which they detected from the direction of Cyg X-3 had practically the same number of high energy muons as normal hadron induced showers, thus making it unlikely that the radiation that they had observed were ultra high energy gamma rays from Cyg X-3. If they are not gamma rays then what are they? The particles cannot be Protons or charged heavy nuclei since at these energies they would be deflected by the galactic magnetic fields and the directionality would be lost. They cannot be Neutrons since the distance to Cyg X-3 is about 10 kpc and the Neutrons of  $10^{15}$  ev would just decay away. They cannot be neutrinos since neutrinos do not have high enough cross-section to produce such showers in the atmosphere and if they did the requisite number would upset all energetics of the source. A new dimension was added to the interest in Cyg X-3 when the SOUDAN group in the US reported the observation of very high energy muons from the direction of this object in their Proton decay detector underground. While the Mont Blanc Proton Decay group has confirmed the observation of high energy muons, the other deep underground groups like the KGF (India), FREJUS (France) and KAMIOKA (Japan) have reported negative results. The IMB group has claimed that on occasions they do see high energy muons from the direction of Cyg X-3. The observation of muons by themselves and as part of air showers if established will be extremely important. As we have already stated they cannot be understood in terms of the incidence of known particles from the direction of Cyg X-3, and may indicate in the environment of Cyg X-3 binary system, the production

of some type of new neutral particles with long life time. It is this aspect that has excited the theoretical particle physicists. For the Cosmic ray physicists Cyg X-3 is perhaps the first identification of a source of this radiation.

### Hercules X-1

Her X-1 is another astronomical object which has been studied very extensively in recent years. It is a binary pulsar with three periodicities : 1.24 second pulsar period, 1.7 day binary period and a peculiar 35 days modulation in which for 11 days the X-ray intensity is high, for 19 days low and for 5 days intermediate high. The companion star of the X-ray object has been optically identified as Hz Hercules and the binary orbit parameters are well determined. A novel feature of Her X-1 is that the cyclotron line feature at 53 Kev has been clearly seen which confirms the X-ray source as a Neutron Star with a magnetic field of  $10^{12}$  gauss around it. Such a binary system with the compact object having such a high magnetic field is the ideal scenario for accelerating particles to Cosmic ray energies. Her X-1 has therefore been searched for emission in the Tev ( $10^{12}$  ev) and Pev ( $10^{15}$  ev) energy domains. The results have been very encouraging. There have been episodes when the source has given evidence for high energy  $\gamma$ -rays. The Durham group recorded a burst activity lasting for about 3 minutes in the Tev range and also found evidence for the 1.24 sec. pulsar modulation. The Whipple Observatory has also seen periodic emission from this source. The extensive air shower array Fly's Eye, in Utah has recorded occasionally showers whose primary energy is greater than  $5 \times 10^{14}$  ev from the direction of Her X-1. The most spectacular results on this source in the Tev range have come from the observation of the TIFR group at Pachmarhi in Madhya Pradesh. Their results are shown in the Fig.(6). On the night of April 11th 1986 they recorded a very large excess (corresponding to  $42\sigma$ ) for a period of about 20 minutes from Her X-1 which is so far the best  $\gamma$ -ray signal that has been obtained from any source in the Tev energy range. The Los Alamos group have also recorded at air shower energies episodes of excess from the direction of Her X-1.

# PACHMARI - BURST ON April 11, 1986

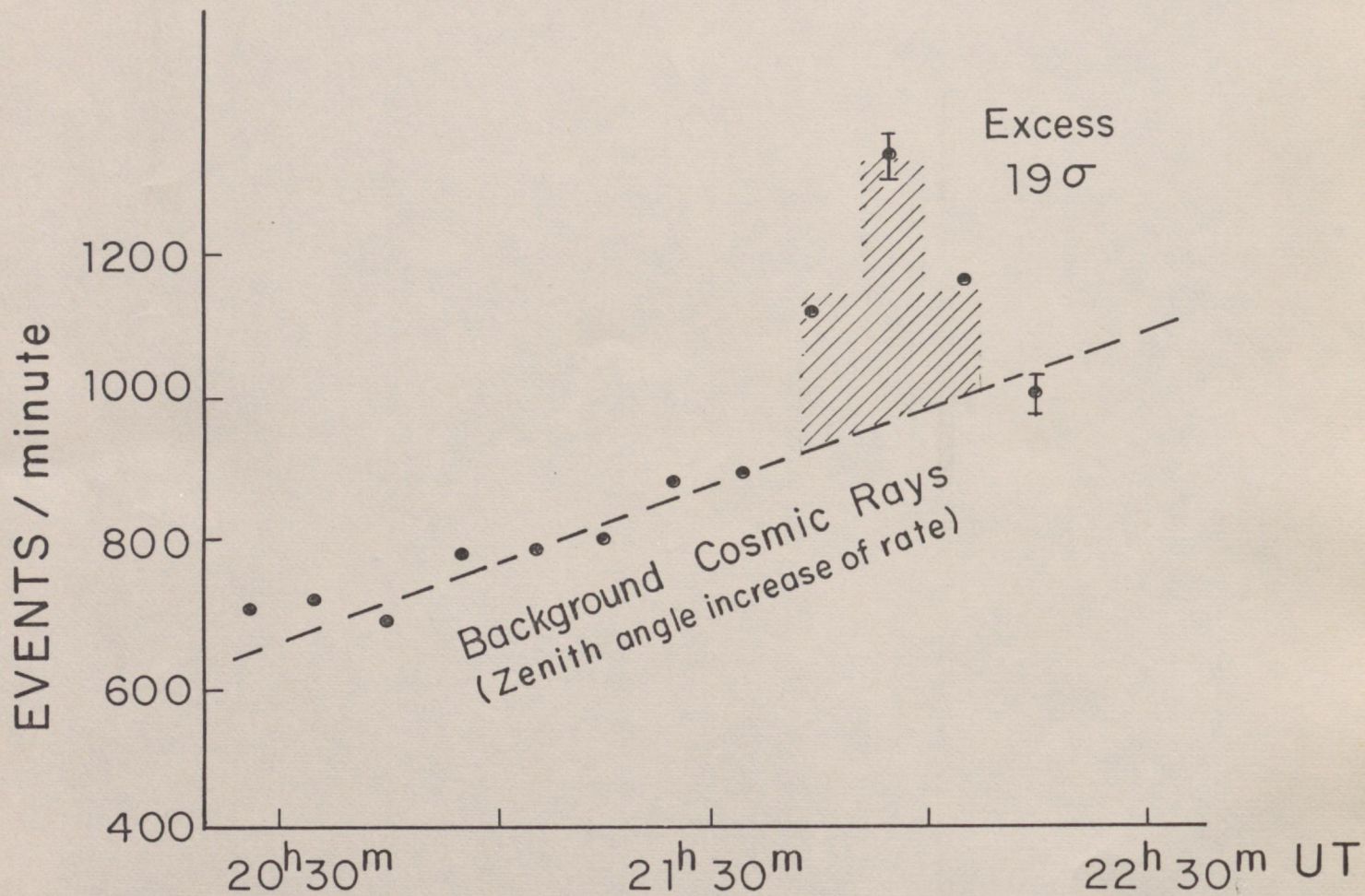


Fig.6. The Ultra High Energy (TeV) Gamma ray burst observed from the direction of Her X-1 on April 11, 1986 by the TIFR group at Pachmarhi. The detailed profile studies recorded with the magnetic tape shows that the significance of this burst is at the level of  $42\sigma$  though the counting rate showed  $19\sigma$  effect.

An interesting aspect of their observation is that the muon content in the showers is comparable to the normal hadron induced showers. Also the pulsar period that they obtain is slightly different from the X-ray period and close to that of the Whipple Observation in the Tev range.

In conclusion I would like to emphasize that the scope and methodology of astronomical studies have undergone radical transformation with the advent of space technologies. We have become aware of a whole range of new celestial phenomena which are particularly associated with gravitationally collapsed objects like neutron stars and black holes. We have also realised that we have been able to identify less than 10% of the constituent matter and radiation of the universe. What the other 90% is, is the challenge for the future generations. I am happy to say that astronomy is one of the fields of modern science where India has made substantial contribution and there is much greater scope in the future. New large scale astronomical telescopes in the optical, infrared and radio have come up. Space astronomies are also being pursued with balloons and satellites.

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