

THE GLORIOUS X - RAY SOURCES OF THE GOLDEN DECADE OF X - RAY ASTRONOMY (1962 - 1972)

B.V. Sreekantan

INSA Ramanujan Professor

*Tata Institute of Fundamental Research
Homi Bhabha Road, Bombay — 400 005, India*

On June 12, 1962 a group of erstwhile cosmic ray physicists (Giaccoini *et. al.* 1962) sent up a pair of thin window Geiger counters on a spinning Aerobee rocket to an altitude of 230 km to examine whether the moon was a source of X-rays that could be produced either by the bremsstrahlung of the infalling electrons from the Sun or due to fluorescence of the lunar surface material caused by the impact of solar X-rays. They did detect X-rays, not from the moon, but from the most powerful X-ray source ScoX-1 which luckily happened to be in a direction close to that of the moon, and revealed itself. Thus was ushered in yet another astronomy, "the space astronomy".

In the long history of astronomy, there have been many landmarks and turning points which have resulted in quantum jumps in our perception and delineation of the universe. With the introduction of the telescope for optical observations in 1610 by Galileo and the subsequent deployment of the spectroscope behind the telescope, there came about a complete transformation in the comprehension about what really constitutes the starry sky — a hundred billion stars in the Milky Way Galaxy, a hundred billion galaxies that stretch out into vast regions of space and a fairly accurate estimate of the pressures, temperatures and chemical composition of the celestial objects, a reliable measurement of the rate of expansion of the universe as a function of the separation of the galaxies and so on. Radioastronomy which emerged in the early 30's, (a product of technological advances in radiowave receivers and antennas) started pouring in new kind of information in addition to supplementing and complementing many aspects of the visible universe. New vistas opened up through the discovery of objects like radio galaxies, quasars, pulsars, and the existence of vast quantities of neutral hydrogen in the space in between the galaxies revealed through the emission of the 21 cm-line, the all pervasive universal 3^0 microwave radiation, the presence of most complex organic molecules in interstellar spaces and so on. These discoveries have a bearing on fundamental issues like the origin of the universe,

the origin of life, the types of forces of nature and their unification, the connection between gravity and empty space and also on the question of existence of extraterrestrial civilizations.

What has been the contribution of X-ray astronomy in this general context? Has it added anything new to our understanding and perception of the universe? The answer is not difficult to find. Even the discoveries in the first decade of X-ray astronomy (1962 to 1972) made with a few balloons, rockets and the first X-ray satellite UHURU, focussed attention on phenomena that were either entirely new or whose importance had not been quite fully recognised by optical and radioastronomies. Apart from the fact that X-ray investigations deal with physical processes in many cases quite different from those responsible for optical and radio emission, a distinct advantage that this field had was due to the circumstance that X-ray and γ -ray detectors were 'single photon' detectors and had consequently built-in capabilities of very high time resolution which was not the case till recently with optical and radio detection. This facility resulted in the early recognition of fast time variability in both intensity and spectra of X-ray sources, which in turn focussed attention on accreting binary systems, especially those having a collapsed object like a White Dwarf, a Neutron star or a Black hole as one of the companion.

Surprisingly some of the very first X-ray sources discovered had a lot to contribute on many other astrophysical aspects too. The accreting binaries and plerions like the Crab have become the favourite of Tev and Pev astronomers in search of the sources of high energy cosmic rays. Let us discuss some of these early extraordinary X-ray sources in some detail.

Scox-1

The very first X-ray source discovered on that eventful night of 12th June 1962, was not only 10^7 to 10^8 times brighter in X-rays than our Sun, but turned to be the most powerful X-ray source in the sky and has remained so till today even after the discovery of thousands of sources. Imagine what the probability is that by sheer chance the most powerful source is located just next to the moon's direction on an arbitrary night during few minutes of observation. Well that is serendipity.

The angular size and location of ScoX-1 source were determined by the technique of modulation collimators in a rocket flight carried out in 1966 by MIT and AS&E (Bradt *et al.*, 1966) With the position known to a reasonable accuracy, the optical identification became possible with the Mt. Palomar telescope (Oda *et al.*, 1967). It turned out to be a 12.5 Magnitude Star, an object that had not made any impression on the optical astronomers till then. There is a story (apocryphal?) that the Caltech astronomer Sandage when he first started looking

at this source was so surprised by its blue richness and variability that he almost fell off from the stool on which he was sitting !

Though no pulsar has yet been identified with ScoX-1, there is clear evidence for doppler shift of spectral lines and time variations which suggest a binary structure for the source, with a period of 0.787 days. The source is too far away for resolution of the companions. Simultaneity of optical and X-ray variations and lack of any delay between the signals has been interpreted in terms of the optical emission arising from the bombardment of X-rays on the matter of the accretion disc close to the neutron star, rather than due to the bombardment of X-rays on the companion object. One of the hallmarks of ScoX-1 type behaviour is the observed correlation between X-ray intensity and spectral shape. Yet another interesting feature of ScoX-1 has been the discovery of the associated Quasi Periodic Oscillations-the QPO activity which is generally supposed to be due to the interaction of the magnetosphere with the accretion disc whose period of revolution is not so regular. The radio astronomers look upon ScoX-1 as a mini-quasar. Sco-X-1 is suspected of emitting ultra high energy cosmic rays ($\geq 10^{15}$ eV) on some occasions (Matano *et.al.*, 1988; Torwar *et al.*, 1990). The evidence is not conclusive yet.

Cygx-1

The source which brought X-ray astronomy into limelight is Cygx-1. Right from the time of its discovery in rocket and balloon experiments in the 60's it was known to be a variable source and observations with the first X-ray satellite UHURU of time variations right down to fractions of a second (Giacconi *et. al.*, 1974) made it an extraordinary object. With the identification of the optical counterpart it became evident that it is a binary system with 5.6 day period. The determination of the binary parameters enabled mass limits to be set of the components. A very conservative mass of the X-ray emitting object is $> 3M_{\odot}$. The companion mass is very much higher. With these characteristics Cygnus X-1 became the first candidate for a Black Hole. Even after almost two decades, it still remains the best candidate satisfying the criteria of bimodal spectra, ultra soft high state, power law tail and flickering in time intervals less than 10 ms that have now been prescribed for classification as black hole candidates. The HEA 0-3 γ -ray data on Cyg X-1 reveals a complex 3-state spectrum that extends up to 1.5 MeV. The spectrum in the low state contains a broad 'bump' centered around 1 MeV which may perhaps be also a signature of a black hole. The other candidates for black holes discovered subsequently which, however, do not satisfy all the criteria listed above are A0620-00, LMCX- 3 and LMCX-1. Very recently the GRANAT satellite has thrown up several sources in the centre of the galaxy which are black hole candidates. The spectrum and other properties of IE 1740.27-2042 are very similar to CygX-1. Yet another similar source is GRS 1758-258.

TauX - 1 The X-ray source in the Crab

The first hard X-ray source to be discovered in a balloon experiment (Clark, 1965) was the Crab Nebula a rapidly expanding hot web of gas identified as the leftover from the explosion of a Star in constellation Taurus in 1054 A.D. Immediately after the discovery of X-ray sources, the possibility that these could be neutron stars with temperatures of more than 10 million degrees had been suggested by astrophysicsts like Chiu, Hayakawa, Shklovsky. At the instance of Shklovsky the NRL group (Bowyer *et al.*, 1969) conducted a rocket experiment on July 7, 1964 to measure The angular size of the X-ray emitting region of the Crab Nebula using the rare opportunity of a lunar occultation of the Nebula on that day. The experiment showed that the X-ray emission came from a broad region, presumably the Nebula itself. Consequently, the hypothesis of neutron star as the X-ray emitter was discredited. Ironically, however, a few years later the 3 3ms pulsar showed itself in radio observations of the Crab Nebula by Comella *et al.*(1969). The slowing down rate of the crab pulsar fits exactly what is expected of a rotating neutron star losing energy by radiation. The magnetic field of the neutron star is estimated to be $\sim 10^{12}$ gauss. Soon after various mechanisms were proposed for acceleration of particles in such environments of high magnetic fields around rotating neutron stars.

In the early 50's the high intensity of polarized optical radiation from the nebula had been interpreted by Shklovsky as synchrotron emission by electrons gyrating around the magnetic fields of the filaments of the nebula which were thought to have a strength of $\sim 10^4$ gauss. On this basis the energy of the electrons is $\sim 10^{12}$ eV. It was obvious that if electrons of such high energy are there in the nebula, then the same accelerating mechanism should operate on protons as well. If such high energy protons are there they should give rise through nuclear collisions, to high energy π^0 s. In this way it was argued that Crab Nebula may be a source of very high energy (TeV) gamma rays. Early experiments in the late 50's and early 60's using the night air Cerenkov technique only succeeded in setting upper limits to the steady flux of TeV energy gamma rays from the crab nebula and other supernova remnants.

With the discovery of the Crab Pulsar, pulsating in optical, radio, X-ray and gamma rays the distinct possibility that it may be pulsating in TeV energies also became a strong conjecture. Fresh attempts with larger areas of air Cerenkov detectors provided with fast electronics for timing the individual pulses to high accuracy to enable pulsar analysis, began at several laboratories in the world including the cosmic ray laboratory, Ooty.

The nebula was found to be only a transient source of TeV gamma rays— most of the time the transient emission was pulsed (Grindlay, 1972; Gupta *et al.* 1978).

Very recently, the Whipple Observatory group (Lang *et al.*, 1991) in USA has had a real breakthrough in this area of astronomy. Using the Cerenkov imaging technique which has enabled them to reject 98.5% of the cosmic ray background proton induced showers, they have established that the Crab Nebula is a steady emitter in the TeV range. What is most surprising is that there is no indication yet of any pulsed emission. In the still higher energy domain of 10^{15} eV, where also large scale experiments are searching for emission from objects like the Crab Nebula, there has been very recent recording of an 'episodic emission'. Four air shower groups the KGF (Acharya *et al.*, 1990), the Baksan (Alexeenko *et al.*, 1991), the EASTOP (Aglietta, 1991) and the Tien Shan (Chudakov, 1990) recorded a PeV burst lasting several hours from the Crab on the February 23, 1989. The KGF results show that the PeV emission is pulsed and also that the number of muons in the showers are not different from the background cosmic ray hadron showers while pure x-ray cascades should contain not more than 10% of muons compared to the number in hadron showers. This feature of muon abundance raises several important questions. Are gamma ray interactions at PeV energies different from pure electromagnetic interactions? Are the primaries of the showers neutrinos which interact at PeV energies with hadronic cross section? Or is the crab emitting some unknown type of strongly interacting neutral particle?

Cygx - 3

CygX-3 entered the catalog of astronomical objects in 1966 as one of the brightest X-ray sources discovered in that decade. The first X-ray satellite UHURU (Giacconi *et al.*, 1974) and later Copernicus revealed a 4.79 hour periodicity in X-rays and was obviously interpreted as a binary system. However, no pulsations were recorded from this source. Attempts at radio identification revealed that it was a very weak radio source. On September 2, 1972, a Canadian astronomer by sheer chance observed that the radio intensity of the source had increased by a factor of 100. This sudden increase was confirmed by other observers. The intensity decreased after 10 days. Since then a radio watch has been kept on this source and it has been found that the source does become bright and goes into a mode of flaring activity about once a year (Braes and Miley, 1972; Gregory *et al.*, 1972). The Gamma ray satellites SAS II and COS-B, however, gave contradictory results. While the SAS II reported observing the 4.8 hour periodicity in the 40 MeV range, the COS-B did not see any flux from the source at all. Since CygX-3 is located at the edge of the galaxy and is beyond a dusty spiral arms it cannot be seen optically. It has been picked up as 11th or 12th Mag IR star and is consistent with a blue giant at a distance of ~ 10 pc.

The Crimean astrophysics observatory group (Stepanian, 1979) reported the observation of TeV gamma rays from the direction of CygX-3 with a period of 4.8 hours during September 5th-November 1972. Radio bursts had occurred on September 2, 19 and 22. This observation of the Crimean group was later confirmed by many other groups who were also using the night air Cerenkov technique for TeV observations. It was clear that it was not a steady source, but flared up occasionally. In 1983 the Kiel group (Stamm and Samorski, 1983; Samorski and Stamm 1988) reported at the 18th International Conference on Cosmic Rays at Bangalore the observation of a 5σ excess from the direction of CygX-3 in extensive air shower data ($E > 10^{15}$ eV) collected over a period of 3 years from 1976-79. The Haverah Park air shower group (Lloyd — Evans *et al.*, 1983) in the U.K. also confirmed these observations based on their extended data of 79-84. It was found that the PeV emission was phase modulated with the 4.8 hours periodicity and peaks occurred around two phases 0.27 and 0.63. Since 1983, CygX-3 has been the object of study by several groups in the world. Not all have reported positive results. There have been reports of occasional flaring activity (Alexeenko *et al.*, 1987; Dingus *et al.*, 1988). The Durham group (Bowden *et al.*, 1991) has reported seeing 12.59 millisecond pulsar activity in the TeV range.

An anomalous, but very significant feature of the Kiel observation was that the excess showers from CygX-3 had about the same content of muons as normal hadron induced showers. If the primaries are photons, then the muon content must be less by a factor of about 10. Then came another surprising result. The Soudan group (Marshak *et al.*, 1985 a,b) reported in 1985 the observation of muons of energy > 0.7 TeV (not necessarily associated with air showers), from the direction of CygX-3 with their Proton Decay detector operating at a depth of 2090 m.w.e. A similar observation of muons (> 5 TeV) was also reported in the Mont. Blanc tunnel Proton Decay experiment by the NUSEX group (Batistoni *et al.*, 1985) operating under an overburden of 5000 m.w.e. Both these observations were made during 82-83. Some other groups like the IMB (Bionta *et al.*, 1987), Frejus (Berger *et al.*, 1986) and Kamioka (Oyama *et al.*, 1986) did not see any excess in muons. The observations of IMB and Frejus coincided with the period of observation of Soudan. The upper limit set by IMB is not in conflict with Soudan. Further the Soudan group (Marshak, 1987) reported the observation of a short duration burst of muons ($> .7$ TeV) during radio flare period of September '85.

Very recently, there have been further reports of muon burst events from the CygX-3 direction during the large radio flare period of January 19-25, 1991. The Soudan group (Thomson *et al.*, 1991) has seen excess of muons on the 20th and 23rd January and the KGF group (Private communication) on 18th and 19th

January. The muons seen in the KGF experiment have energy > 8 TeV. The HEGRA (Merch *et al.*, 1991) extensive air shower array at La Palma has also reported an excess of PeV air showers at a 4σ level and the AKENO (Hayashida *et al.*, 1991) air shower array a cumulative excess of showers of energy greater than $E \leq 10^{17}$ eV, (EeV) over a 50 days period which includes the radio burst period.

Her X - 1

Her X-1 was discovered (Tananbaum *et al.*, 1972) by the first X-ray astronomy satellite UHURU. It was first seen as a hard X-ray source by TIFR group (Manchanda *et al.*, 1973) in their balloon flights from Hyderabad. There are three distinct periodicities associated with this source: 1.24 second pulsation; 1.7 day binary orbit period and a 35 days cycle that modulates the intensity of the source in an irregular fashion of approximately 9 bright days and 26 dim days. The companion star HZ Hercules has been identified and the reprocessed IR and optical pulses are seen from the companion. A very important landmark was the discovery of the 53 keV line feature (Trumper *et al.*, 1978) which is clear evidence for cyclotron emission; for the first time this result established unambiguously that the magnetic field in the neighbourhood of the neutrino star is $\sim 10^{12}$ gauss. The slowing down of the Pulsar period in Her X-1 is occasionally erratic. The pulse profile in X-ray emission is also not steady. Her X-1 has been detected as a pulsed TeV source on occasions. (Dowthwaite *et al.*, 1968; Weekes, 1988). What is intriguing, however, is that often the pulsar period in TeV emission is shorter by $\sim 16\%$ compared to the period in X-rays. One of the most pronounced TeV bursts lasting ~ 20 min. has been recorded from Her X-1 by the TIFR group (Viswanath *et al.*, 1989) operating in Pachmarhi. Pulsed PeV (10^{15} eV) emission has also been recorded on several occasions. (Dingus *et al.*, 1988; Gupta *et al.*, 1990). Here again an anomaly is that the signals do not conform to what is expected of pure γ -ray showers, since the muon content is comparable to hadron induced showers. Also the pulsar period is close to the period observed in TeV emission.

The Active Galactic Nuclei - Quasars, Seyferts, BL Lacerta, Cataclysmic Variables

One of the first extragalactic X-ray source to be detected is the quasar 3C273 in rocket experiments. As early as 1971, UHURU (Gursky *et al.*, 1971), found evidence of X-ray emission from the Seyfert Galaxies NGC 1275 and NGC 4151. In the case of NGC 1275 the X-ray emission of $L_x \sim 10^{44}$ ergs/sc, was equal to the total optical emission of the galaxy and in the case of NGC 4151 the X-ray emission of $\sim 10^{42}$ ergs/sc was comparable to the optical emission from the region of the galactic nucleus. UHURU also established that the Galaxy NGC 5128 at the centre of the radio source CEN-A is a dominant X-ray source.

The notion that the active galaxies are powered by accretion on to super massive black holes has steadily gained ground. The black hole mass could be as high as $10^6 - 10^9 M_{\odot}$. The dynamical time scales in these are of the order of 100 sec, the mass accretion rate about a Solar Mass per year.

In the case of NGC 6841 time variations in intensity have been observed over time scales of a few hundred seconds. Many seyferts have shown time variations on the scale of days. In the case of NGC 4151 an X-ray flare event that lasted for less than an hour has been registered. These variations indicate that the size of the X-ray emitting region is small, $\sim 10^{15}$ cm, supporting the hypothesis of giant black holes at the centres of these objects.

The spectral features of AGN show roughly comparable amounts of power in each logarithmic interval of energy in the UV and high energy X-rays extending to the γ -ray regions of 1.5 MeV. However, there is a pronounced 'UV bump' peaking at 10eV, followed by a power law X-ray spectrum. Adopting the scenario that AGN's have a fast rotating accretion disc around a giant black hole and an accretion shock is formed due to the infall of matter at some distance in which gravitational energy is converted into highly relativistic particles, some theorists (Stecker *et al.*, 1991) have speculated that the AGN's could be source of very high energy neutrinos, in the energy range $10^{14} - 10^{20}$ eV. What is encouraging is that the intensities of neutrinos so calculated seem to fall within the range of detection possibilities with the deep ocean water cerenkov detectors (DUMAND) (Stenger γ) that have been planned. This opens up the exciting possibility of TeV-PeV neutrino astronomy. Possibilities of using the several kilometer deep ice formations in the Antarctic are also envisaged. (Barwick *et al.*, 1991)

The first X-ray satellite UHURU launched in 1970 revealed some 400 X-ray sources in the sky. Over the last two decades fifteen X-ray satellites have been launched carrying a variety of instruments — proportional counters, gas scintillation counters, imaging telescopes with changeable focal plane instruments. There have also been a large number of balloon experiments for study of hard X-rays. These have established that every known class of astronomical — objects — stars, binary systems, RSCV n binaries, supernova remnants, ordinary galaxies, radio galaxies, seyfert galaxies, QSO's are all X-ray emitters at varying levels of power output. A large number of X-ray bursts have been detected and their detailed time profiles studied. There has been a special focus on compact X-ray sources in globular clusters and low mass binaries in the galactic bulge. Neutron star masses have been determined. Several candidates of black holes identified. Many extragalactic sources have been studied. It is estimated that the latest X-ray satellite ROSAT that has gone into orbit will detect

about 10^5 sources and locate them to an accuracy better than 1 arc min. The preliminary results from ROSAT seem to confirm evolutionary Cosmology.

While prospects in X-ray astronomy had been foreseen to some extent, there was absolutely no prediction of any such prospects in the field of X-ray astronomy. It is a supreme example of a major new area of astronomy that got opened up through the exploitation of the state-of-art technology, that too by non-astronomers. This development has brought about a new culture into astronomy which had remained an exclusive field of professional astronomers. Now even those who are not professional astronomers by training, are welcome into the astronomical circles. Also it has transformed the theoretical astrophysicists from just making timid and safe predictions to indulge in bold and radical predictions. The advantage of all this transformation can be seen when we realise that what we know about the universe is still perhaps much less than what we do not know. Let us hope the ever progressing newer technologies will enable us to take a much greater step towards a deeper understanding of the still mysterious universe.

Abstract

Starting with the serendipitous discovery of ScoX-1 in June 1962, the survey of the sky with rockets, balloons and the first X-ray satellite UHURU, revealed a large number of X-ray sources in the very first decade of X-ray astronomy. Some of these early X-ray sources proved to be of great interest over the entire spectrum of the electromagnetic radiation revealing many new aspects of high energy astrophysics. Of particular significance was the focus on transient phenomena and the role of accreting binary systems involving collapsed objects like neutron stars and black holes. The special features of some of these early X-ray sources are discussed—especially those that have turned out to be very High and Ultra High Energy Gamma ray sources too, indicating the possibility that the century old problem of the sources of cosmic radiation is nearing a solution. The possibility of Very High Energy Neutrino Astronomy has also opened up.

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THE PICTURE OF THE HELIOSPHERE

D. Venkatesan

*Institute for Space Research
Department of Physics and Astronomy
University of Calgary
Calgary, Alberta, Canada T2N 1N4.*

Introduction

Cosmic rays were discovered about 80 years ago. During a little over the past three decades, the study of the time variations of cosmic rays has been transformed into an investigation of the same both over time and space. It has been a useful tool for probing the interplanetary region born with a new name - "*The Heliosphere*". *In-situ* observations by the four man-made spacecraft, Pioneers 10 and 11 (P10 , P11) and Voyagers 1 and 2 (V1, V2), have enlarged and enhanced our understanding of the heliosphere to a large radial distance from beyond the orbit of earth (1AU).

For the first time, we are now about ready to traverse the inner area of the heliosphere (< 1AU). The recent launch of spacecraft, Ulysses on October 6, 1990 will, over the next decade, assemble data of the unexplored and uncharted regions, especially over the solar polar space. This spacecraft, named after the legendary Greek hero, has been the result of a partnership between the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA). The heliosphere would now be completely investigated, so that we gather information about the physical conditions and processes that we have not been able to study so far. This article deals with the entire heliosphere, its true extents and its boundary (heliopause).

Heliosphere : (Early Perceptions)

The space surrounding the sun, perhaps a little further than the last known planet, Pluto, used to be called the interplanetary medium; the present day terminology for the same space and up to a distance of some 100 — 150 Astronomical units is now the Heliosphere. It has been realized that solar activity controls and modulates the character of this region.

Concept of the size of this heliosphere, has had a remarkable upward progress. The late 1960's and early 1970's was an interesting period in our perception of the same. A scale size of the modulation region of cosmic rays around the sun (heliosphere) was taken to be about 2 — 5 AU in radius. This was the time when