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Space astronomy in India: 43 years and counting

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Abstract. The beginning of Space astronomy in India took place at TIFR in 1966, with the development of a small balloon borne X-ray astronomy payload. During the 1966-1976 period, studies in the X-ray and Gamma ray energy bands were pursued both at TIFR and PRL, Ahmedabad. Infrared astronomy made its beginning in 1975. The rapid progress of Space astronomy in the early years was mainly due to the availability of large plastic balloons and detector tools developed by the High altitude studies group of TIFR, which I joined in 1966 and initiated the fabrication of the X-ray payload. Balloon borne astronomy has thrived during the past 43 years while satellite opportunities during this period were few and only for piggyback payloads. At present, a full fledged multi-wavelength astronomy satellite mission named ASTROSAT is under fabrication and will be launched in 2011.

Keywords : X-ray astronomy, Space astronomy, Balloon borne experiments, History of astronomy

1. Early phase

Space astronomy in India was born in 1966 at TIFR as a Balloon-borne exploratory programme soon after the chance discovery of the first X-ray sources in 1962 and within one year became the key project of the High Altitude Studies group. Simultaneously, balloon borne X-ray and gamma ray astronomy work started at Physical Research Laboratory, Ahmedabad. In the early phase

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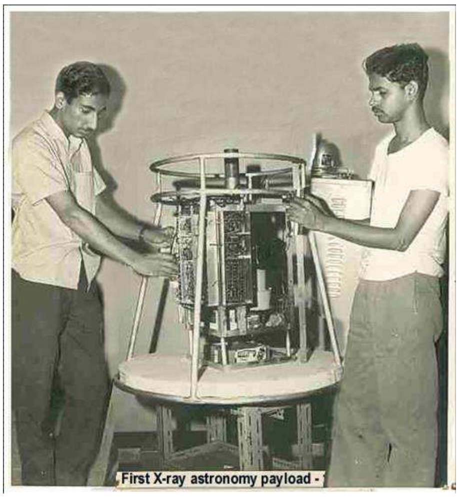


Figure 1. First X-ray astronomy payload flown on March 12, 1967.

of 1966-1975, a variety of instruments were developed and launched on Balloons, Rockets and the early satellites. Studies in far infrared astronomy using balloon borne platform matured with the first flight in 1975. During the early phase of X-ray astronomy, the instruments were simple and had low sensitivity due to large detector background produced by cosmic ray interactions in the atmosphere at balloon altitudes. The location of the TIFR balloon facility at Hyderabad (lat. 17.6^oN) gave us a distinct advantage due to high cut-off rigidity for the charged particles and therefore the detector background was relatively low.

This enabled the group to plan detailed spectral and temporal studies of known objects, survey for new sources and the measurement of the diffuse X-ray spectrum using growth curves, which were the key objectives during the late 60's and early 70's. The X-ray astronomy payload at TIFR during the pre-1976 phase consisted of a NaI(Tl) scintillation counter with 100 cm^2 area, 4mm thickness and having a beryllium entrance window. The crystal assembly was surrounded both by cylindrical plastic scintillator and passive collimators with a FOV of 25^o. The pulse height analysis of the accepted events was done in 16 channels corresponding to the operating energy range of 15 to 150 keV. Gradually, the number of detectors in the payload were increased to seven with a total area of $\sim$1000 cm^2 and hexagonal passive collimators $12.5^o \times 12.5^o$ were used.

Early experiments were devoted to the observation of hard X-ray spectrum for the two known bright sources Sco X-1 and Cyg X-1 and the search for new sources. Fig. 2 gives a sample of the spectral data on Sco X-1 and the celestial distribution of the observed hard X-ray photons.

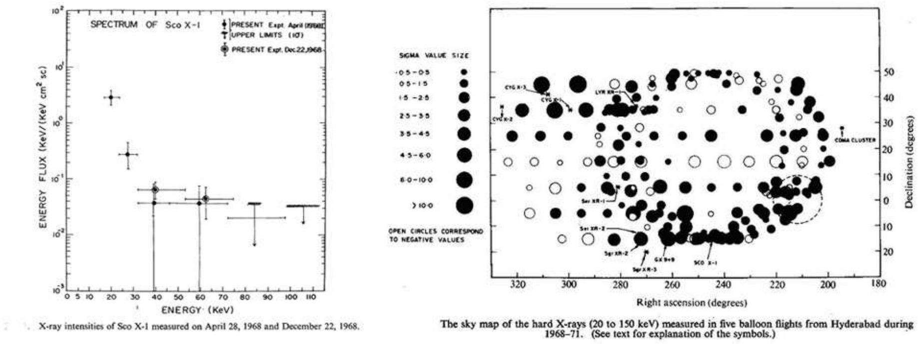


Figure 2. Early results from TIFR experiments: hard X-ray spectrum of Sco X-1 and New discovered source TWX-1 in Coma constellation.

An experimental programme using Phoswich detector made with NaI(Tl) and CsI(Na) scintillators in collaboration with the Univ. of Calgary, Canada became operational in 1977. The instrument was made using four detectors with a total area of 400 cm^2 and a field of view of $11^o \times 11^o$ and was flown successfully in 1979 for the observation of X-ray sources in the 20-120 keV energy band. Phoswich technique helped in eliminating the Compton scattered events in the main detector using rise-time selection technique and thereby reducing the detector background. The FOV was later changed to $5^o \times 5^o$. After several successful campaigns, the instrument was lost during the 1988 flight and the payload was not rebuilt.

Even though the discovery of X-ray window to the universe was serendipitous event but during 50's and 60's the conditions were ripe for it to happen anytime. Second world war had generated a large number of scientific and technological breakthroughs in its wake. This progress led to a string of milestones in astronomy being achieved in quick succession. For example;

1949	The completion of the Hale 200-inch telescope at Mount Palomar
1951	Discovery of 21.-cm hydrogen line in radio waves
1955	completion of 250 ft radio telescope at Jordal bank
1957	Launch of the Sputnik, the first artificial satellite
1959	Russian satellite landed on the Moon
1962	Birth of X-ray astronomy

The decade between 1950-1960 was the Golden period for astronomy during which many major facilities were established and the experiment in upper space became a reality with the launch of Sputnik in 1957 (see box).

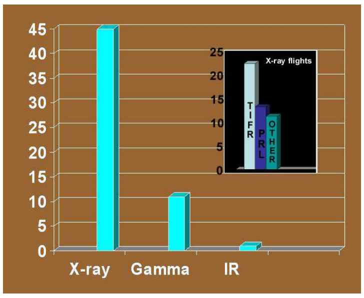


Figure 3. Bar plot for the balloon flights made during 1966-1976.

In spite of limited resources and unavailability of modern computational and hardware techniques, the experimental activity in space astronomy during the 1966-76 period was very intense. A large number of successful flights were made and many new path-breaking results were obtained. These include; (i) Sudden changes in the intensity of Sco X-1 (ii) Observation of hard X-ray flare in Cyg X-1 (iii) Discovery of two new sources, one of which was later identified with the first AGN (NGC 5506) (iv) Intensity and spectrum of the diffuse cosmic X-ray background (v) Hard X-ray spectrum of Her X-1 and possibility of added flux due to cyclotron emission (vi) Hard X-ray spectrum of the galactic center region, Transient source AQL X-1 and many more. A bar plot of the 56 balloon flights conducted from Hyderabad during the 1966-76 period for X-ray/ gamma ray astronomy is shown in Fig. 3. As is seen from the plot, 45 of these experiments corresponded to observations in the X-ray band and 24 of these were conducted by the TIFR group. Another key input to the early space astronomy programme at TIFR was a series of balloon based experiments in collaboratiion with several International groups from Japan (Nagoya Univ & ISAS), SAO and Univ of New Hampshire from USA. As seen in the bar plot, 10 such flights were made and important results like the size of the X-ray source in Crab nebula measured during Lunar occultation and anti-correlation of the variability of X-ray emission of Sco X-1 with the optical band emerged from these experiments.

Rapid progress of space astronomy at TIFR in its early days was mainly due to an existing parallel programme of balloon design and fabrication in the Plastic Balloon Section of the Institute, which also had the necessary infra-structure for balloon launching from different locations and its recovery. The growing needs of larger and heavier payloads and the requirement to reach high altitude of 3-5 mbs was provided with the development of indigenous large balloons. The National Balloon Facility at Hyderabad is a centre of excellence in scientific ballooning and currently manufactures a wide variety of large balloons, the largest among these is 740.000 cu m which has the capability of carrying a 600 kg payload to 42 km ceiling altitude. A brief historical account

Figure 4. Homi Bhabha seen with his early cosmic ray experiment.

of the development of single cell polyethylene balloons is given in the box for reference.

Two payloads using scintillation counters were also built by PRL groups for the study of Cosmic X-rays and the Gamma rays. These flights were also launched from the TIFR balloon facility at Hyderabad.

Cosmic ray studies in 40's and early 50's were conducted using latex balloons for high altitude observations. Driven by the need to better understand the environment of the upper atmosphere and conduct experiment at stratospheric heights, the efforts were initiated in the United states to build large single cell polyethylene balloons. The American armed forces sponsored the research in balloon technology after the war, to study problems to be faced by future military pilots, and eventually, astronauts venturing into space. American Navy sponsored the Strato-lab project in 1954; as the training programme for manned balloons to the upper atmosphere and the first successful flight above 40,000 feet (12,192 meters) was conducted in 1956. A parallel programm code named 'Manhigh' was sponsored by the American air force for similar goals.

The cosmic ray group of TIFR was also using a train of Latex balloons for high altitude observations with gieger counters and nuclear emulsions during the 1945-55 period. Figure 4 shows Dr. Bhabha and Dr. A S Rao releasing one such payload at launch. Realizing the importance of single cell large Scientific balloons made from plastic material, for high altitude studies up to the stratosphere, the development of single cell tear-shape polyethylene balloons was started in TIFR in 1956. First successful balloon flight took place in April 1959 from Mumbai. Stratospheric balloon flights were later conducted from many stations with in the country from Kashmir to Madras, including the Osmania University Campus in Hyderabad, a place that would become the main balloon launch site in the decade that followed. Permanent campus of TIFR balloon facility at Hyderabad started functioning in 1970 and became National balloon facility in 1980.

Figure 5. T100 cm IR telescope instrument on the launch truck.

With the invention of IR bolometer and array detectors, space borne infrared window to the universe opened for astronomical observations. TIFR group quickly got into the act and an IR telescope was built using a 30 cm mirror and liquid helium cooled bolometer working in the far infrared band of 250 microns. The balloon payload consisted of servo stabilized platform using a star tracker and the IR telescope. The first successful flight of the Mark I instrument was made in April 1975.

During the phase II of balloon borne X-ray astronomy, a new programme started in 1977, to develop large area xenon filled proportional counters for hard X-ray energy. A payload consisting of two large area multi-layer, multi-cell proportional counters having a thin aluminum window and a geometric area of 2400 cm^2, and a $5^o \times 5^o$ slat collimator made out of Tin became operational in 1981. The detectors were filled with a mixture of xenon, argon and methane gas in proportion of 80:10:10 at a total pressure of 1000 torr thereby making the effective energy range of detection between 20 to 80 keV. The energy resolution of the detectors was 11% at 60 keV. With the large area and better energy resolution, the Xenon counter experiment was suitable for the study of weak X-ray sources and the X-ray spectral lines in the hard X-ray region. This payload was flown successfully several times during 1981-1996 and some of the key results from these observations were about X-ray pulsars and X-ray binary sources.

In the case of IR astronomy, the telescope size was enlarged initially to

75 cm Mark II telescope and later to a 100 cm telescope (T100). Several successful flights have been made using the T100 instrument and a large number of star forming regions have been observed. Over the years, different focal plane instruments have been used with this telescope. The flight ready IR payload weighs about 1200 kg and is seen in Fig. 5.

1.1 Rocket astronomy

Rocket based experiments were conducted by both, the PRL and TIFR groups during the 1967 -1985 period. The PRL group took the lead in building a small proportional counter experiment operating in the 2-6 keV energy band, which was launched on a spinning rocket from Thumba rocket launching station (TERLS) in 1968. Larger payloads were later launched from Sriharikota Space centre (SHAR). Rocket based experimental activity in the country was limited because the payload was lost into the sea after every flight and it took several years to rebuild the entire payload afresh, unlike in the USA, where rocket flights were conducted from the White Sands rocket range and the payload was recovered with a parachute. Rocket based programme at TIFR commenced in 1970 and ended in 1982 and observations were confined to the extremely soft X-ray energy band of 0.1-6 keV.

Early experiments for TIFR payloads were done using Centaur rocket from TERLS while later payloads in 1979 and 1982 were launched on the Rohini Rocket from SHAR centre. The rocket payload of TIFR mainly consisted of two home-made multiwire proportional counters with 400 cm^2 area and $8^o \times 8^o$ field of view, arranged back to back along with the processing electronics. During the 1974 and 1976 flights, the detector entrance window was 6 micron polypropylene coated with carbon having an energy range of 0.1-6.5 keV. During the 1979 and 1982 flights, the area of the detector was increased to 680cm^2 and the window thickness was reduced to 1.5 micron polypropylene, thereby increasing the transmission of the input flux. For one detector, the window was

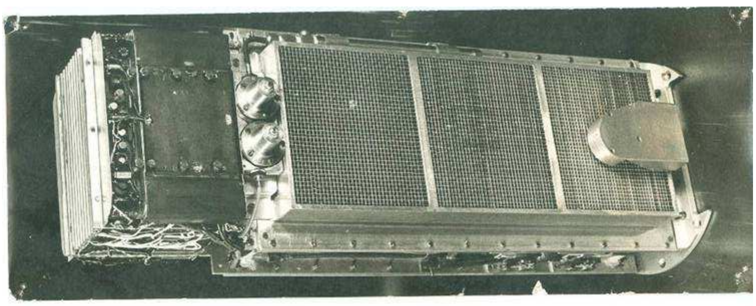
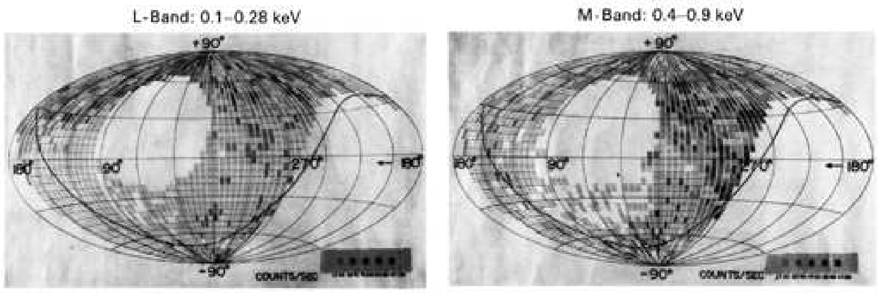


Figure 6. Soft X-ray payload flown on RH 560 rocket.

coated with Carbon and the second was Boron coated to act as narrow band pass filters. The field of view was $5^o \times 5^o$. The respective detection threshold (4σ) of the two instruments, for discrete sources with 1 sec integration was 1×10^{-10} and 3×10^{-11} in units of ergs cm^{-2} s^{-1} keV^{-1}.

A photograph of the assembled payload launched during the 1979 and 1982 campaign flights is shown in Fig. 6. In a short flight of few hundred seconds, a spinning rocket only scans a narrow belt in the sky and therefore gives only a limited coverage. In the flight launched in 1979 and 1982 using RH-560 rocket, a precession of payload was introduced with the help of a yo-yo mechanism soon after the nose-cone separation. This procedure allowed us to scan a large part of the sky during one flight and high quality data was obtained on the spatial distribution of the soft X-rays in the sky. A sample plot of the two energy bands obtained during the 1979 flight is shown in Fig. 7. The density of grey colour in the plot represents the intensity of the diffuse X-ray emission in the corresponding energy band.



(a) (b)

Figure 7. Soft X-ray distribution in the sky.

1.2 Satellite astronomy

The launch of a small satellite mission carrying proportional counters and code named UHRU by the Harvard-Smithsonian group in 1971, marked the beginning of satellite based X-ray astronomy and was later followed by several small satellites in quick succession e.g. SAS-3, ANS, ARIEL 5 etc. A large number of satellites with a variety of instruments have been in orbit since then and several new discoveries mainly in the soft X-ray band have emerged from these experiments. Over the years the X-ray and gamma ray instruments have become extremely heavy, more sophisticated and provide data for spectral imaging and temporal variability of the stellar, galactic and extragalactic sources. The currently operating X-ray missions are the Chandra observatory and the Newton telescope for X-rays and Fermi in the gamma ray band.

Figure 8. X-ray sky monitor launched on second Indian satellite BHASKARA.

Satellite based observational opportunities for Indian groups have been extremely few until now. Most of these early payloads were small piggy-back instruments riding along side the main payload and therefore, were highly constrained both in size, power, and sensitivity and observational flexibility. A list of the satellite experiments made by the TIFR group up to 2008 is given in the table. The photograph in Fig. 8 is the All sky monitor built for the BHASKARA satellite which was launched in 1979 on a Russian rocket. The payload used a pair of position sensitive anodes and was configured as a 2π pin-hole camera with $5^o \times 5^o$ angular resolution. The payload weight was only 3.4 kg and used 1W of power.

Table 1. Indian satellite borne experiments until 2008.

Launch date	Mission	Instrument
1975 19/4	Arayabhatta	Solar X-rays and gamma rays
1979 07/6	Bhaskara	X-ray All sky monitor
1992 20/5	SROSS-C	Gamma ray bursts
1996 21/3	IRS P-3	Pointed mode proportional counters + All sky monitor
2003 08/5	GSAT-2	Solar X-ray spectrometer

2. Present canvas

2.1 Balloon borne research

Present day balloon-borne payloads are large, heavy and probably more complex than even satellite payloads, both in construction as well as in operation.

Figure 9. LASE assembly.

A typical balloon-borne payload consists of several sub-systems of which the detector telescope, front-end electronics for pre-processing of the data, on-board data storage, on-board power supply, telemetry and telecommand form the major segments. Due to its requirement of remote operation a built in intelligence for autonomous operation is also essential in case of RF link failure. For instruments used for astronomical observation, a highly stabilized platform and on-board star tracking sub-systems are also essential parts of the payload gondola. Since the trajectory of balloon during the flight is along the wind flow direction and is variable, an onboard star tracker has to have in-built intelligence based on GPS system, since the look angles depend on the latitude and longitude of the telescope at a given moment. A highly stabilized UTC time reference is also an integral part of such payloads.

At present balloon borne X-ray astronomy mainly consists of two payloads code named LASE and HEXIT while the two recently developed proof-of-concept payloads are the Lanthanum Bromide detector for high resolution spectroscopy and hard X-ray imaging using zone-plates. Large Area Scintillation counter Experiment (LASE) is designed to detect microsecond variations in the flux of X-ray sources in hard X-rays up to 200 keV. LASE is a third generation payload and uses modular detector design made with a combination of thick and thin NaI(Tl) detector. The telescope consists of three modules of NaI(3mm) and NaI(25mm) crystals, arranged in a back-to-back geometry and having an effective area of 400 cm^2 each. This innovative geometry helped in reducing the detector background by about 95%. The thickness of the two components in our back-to-back geometry are carefully optimized to give better shielding with less detector volume and low dead time. The field of view of each module is $4.5^o \times 4.5^o$ and is defined by a dismountable 1.3 mm thick slat collimator made with a sandwich of Cu+Sn+Pb+Sn+Cu (0.15+0.25+0.5+0.25+0.15 mm). The data is spectrum analyzed in 64 channels between 20 and 200 keV and each event is also time-tagged to an accuracy of 25 microseconds. The estimated sensitivity of the telescope is $\sim 10^{-6} cm^{-2}\ s^{-1}\ keV^{-1}$ for 3 hr. of source observation and is the most sensitive payload in this energy range. LASE payload as shown in figure 9, has been in operation since 1997 and a large number of papers with important results on the rapid variability of galactic and extragalactic X-ray sources in hard X-rays have emerged from various flights.

Similarly, HEXIT - High Energy X-ray Imaging Telescope, is a new balloon-borne hard X-ray instrument, which combines a large area Phoswich Anger camera with a coded aperture represented by an uniformly redundant array (URA) mask pattern. The energy range of operation is 20-800 keV. The detector assembly having 40 cm dia. is made of NaI(Tl) and CsI(Na) scintillator crystals. Since the optimum thickness of the two scintillators in a Phoswich detector depends on the targeted energy range, HEXIT assembly consists of 12 mm NaI(Tl) as the prime detector coupled to a 40 mm thick CsI(Na) crystal. Thirteen 76 mm phototubes are directly coupled to the optical window in a quadrant symmetric fashion. A passive slat collimator made from a graded shield of Cu+Sn+Pb+Sn+Cu (0.15+0.25+0.5+0.25+0.15 mm) is placed above the detector to limit the field of view to $8.5^o \times 8.5^o$. Angular resolution for the imaged data is 0.75^o.

The current balloon borne observations programme in infrared astronomy is a collaborative project between TIFR group and the IR group at the Institute of Space and Astronautical Studies, Japan. The instrument consists of T100 cm telescope of the TIFR group, which is used with the cryogenically cooled Fabry-Perot spectrometer developed by the Japanese group. The various aspects of this programme are discussed elsewhere in this volume.

2.2 Satellite borne astronomy

2.2.1 *ASTROSAT*

A dedicated Indian astronomy satellite code named ASTROSAT designed to carry out multi-wavelength studies of a variety of galactic and extragalactic cosmic sources, is in an advanced stage of fabrication. Several groups within the country are involved in realizing the on-board hardware and software.

The main objectives of this mission are; (i) Multi-wavelength studies of cosmic sources from ultraviolet band (1000-3000 Å) to soft and hard X-ray band in the range 0.3 to 80 keV using 3 different types of instruments, (ii) Spectroscopy of the X-ray sources with low and medium energy resolution

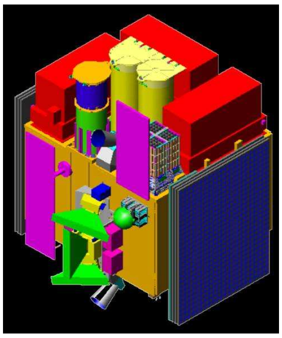


Figure 10. Box model: ASTROSAT.

in the 0.3 to 8 and 2 to 80 keV energy bands. (iii) Study of periodic and aperiodic temporal variations in binary X-ray sources and active galactic nuclei (iv) A continuous sky coverage for the discovery of new X-ray transients and monitoring of the X-ray intensities of bright sources using an All Sky Monitor (v) A near complete sky survey in the ultraviolet and X-ray bands during the first year of operation. Five different payloads proposed to achieve the above mission targets are:

1. Large Area X-ray Proportional Counters(LAXPC) experiment using 3 independent units with Field of view of $1^o \times 1^o$ and total effective area of $\sim 6000cm^2$ and an operating energy range of 3-80 keV.
2. Cadmium-Zinc-Telluride (CZT) Array imaging detector for spectral studies in 10-100 keV band and imaging resolution of 7 arcmin using a Coded mask.
3. A Soft X-ray Imaging Telescope (SXT) made of nested conical foil mirrors with a CCD as focal plane detector for imaging and spectroscopy in 0.3-8 keV band.
4. A Scanning Sky X-ray Monitor (SSM) for detection and monitoring of new and known sources in the 2-10 keV band.
5. An Ultra-Violet Imaging Telescope (UVIT) for a sensitive all-sky survey in UV as well as imaging and spectroscopic studies of cosmic sources in UV band.

Four instruments namely, LAXPC, CZT,SXT and UVIT are co-aligned and will observe each target simultaneously. In addition to the above, a charged particle monitor (CPM) will be launched to provide data on the entry and exit of the Satellite from the South Atlantic Anomaly region. Extremely large flux of charge particles in this region can damage the detectors if in operation. Four instruments namely LAXPC, CZT, SXT and CPM are being developed by TIFR groups, UVIT jointly by IIA/IUCAA and SSM by SAID group of ISRO Satellite Centre.

In terms of the capabilities of various payloads, the large collecting area of the LAXPC's along with 10 microsec time tag will give insight into the physics of accretion disks, mass accretion on to neutron stars and black hole candidates, the secular and episodic changes in the accretion rates and in general, the non-thermal characteristics of the X-ray emission regions in the variety of steady X-ray sources. Light curves and temporal variability of transient X-ray sources, pulsars, micro-quasars, soft gamma ray repeaters (magnetars) and active galactic nuclei will be studied with LAXPC. The CZT detector will provide spectral information in the overlapping energy region of the LAXPC along with imaging of the observed field. The high energy resolution of CZT will also resolve the line emission from the target sources in the hard X-ray region. Similarly, large collecting power and better energy resolution of SXT in the 0.3-10 keV band will complement the hard X-ray data of the proportional counters and will allow us to separate the line emission and the absorption components from the continuum spectra observed by the proportional counters and the CZT imager. Majority of the galactic and extragalactic objects, like coronae of active stars, supernova remnants, accreting white dwarfs, Neutron stars, black hole candidates, active galactic nuclei, quasars and clusters of galaxies emit strong lines-dominated spectra in the soft X-ray band. The study of the line spectra will lead to understanding of the characteristics of the photo-ionized regions, dynamics and the thermal composition of the cold/warm medium, standing shocks and the accretion in their disk geometry. The two UVIT telescopes are configured to provide data in the near and far UV region as well as conventional UBV photometry of the target stars.

The satellite weighing about 1500 kg. will be launched from Satish Dhawan Space Centre using a PSLV rocket and will be injected into a 600 km near equatorial orbit.

2.2.2 *Science with ASTROSAT*

In spite of 45 years of observations in the X-ray window, there are a large number of open problems which need to be resolved. For example, astrophysics of compact objects, emission mechanisms in disks and jets in black hole systems, accretion disc coronae in low magnetic field neutron stars, quasi-periodic oscillations in low mass X-ray binaries, cyclotron line emission, supernovae and nucleosynthesis, origin of gamma ray bursts and the origin of hard X-ray background etc. The choice and configuration of the instruments onboard ASROSAT will provide simultaneous view in different wavelength bands. Multi-wavelength studies of a variety of cosmic sources over a wide spectral band extending over visible, UV (1300 - 3000 or 10 eV to 25 eV), low energy X-ray (0.3 - 8 keV) and high energy X-ray (3-100 keV) bands from simultaneous observations with different instruments will help model the source in complete form. Correlated variations in visible, UV, soft and hard X-ray bands to investigate the origin and mechanism of the emission of radiation in different wave bands. The studies of periodic pulsations, binary light curves, QPOs etc. and aperiodic flaring activity, bursts, flickering and other chaotic variations will be discernible from ASTROSAT data. The variability in X-ray pulsars and other X-ray binaries, coronal X-ray sources, cataclysmic variables (CVs), active galactic nuclei and other active galaxies etc over a wide spectral band covering 0.3-100 keV and with high time resolution will help to reveal the nature of the compact objects and understand the astrophysics of the accretion flows in them. Similarly, the all-sky UV survey will be the first sensitive survey in UV going down to the 20th magnitude.

Broad band X-ray spectroscopic studies for X-ray binaries, Supernova remnants (SNRs), CVs, Stellar Coronae, AGNs and galactic clusters from 0.3-100 keV using SXT, LAXPC and CZT with varying resolving power, $E/\Delta E \sim 30 - 50$ of x-ray CCD in soft X-ray telescope (SXT), $E/\Delta E \sim 6 - 10$ of LAXPC and high resolution $E/\Delta E \sim 50$ for CZT detector array in 50-100 keV band will reveal the non-thermal components in the X-ray spectra as well as will help us to understand the acceleration processes. Spectral studies over a wide spectral band are crucial for discriminating between various models of radiation processes in sources. Scanning Sky monitor will detect and locate new transient X-ray sources and continuous monitoring of known X-ray sources like X-ray binaries, AGNs and other variable sources with SSM. This monitoring will result in detection of long term periodic and aperiodic intensity modulation. For the new bursting and transient sources, the SSM will provide measurements of position to enable pointing of main x-ray instruments at the transient sources for detailed studies of their temporal and spectral evolution.

2.2.3 *RT2-Experiment*

RT-2 Experiment (RT - Roentgen Telescope) is the Indian low energy gamma ray instrument onboard Corona-Photon Mission to study the Solar flares. RT-2 instrument covers the energy range of 15 keV to 150 keV. The payload is a combination of three detectors, two Phoswich crystals and one solid-state imaging detector along with the processing electronics. While the Phoswich detectors will provide the time resolved spectrum, the solid-state imaging detector will provide high resolution images of the solar flares in hard X-rays.

Two Phoswich detector assemblies consist of NaI(Tl) / CsI(Na) scintillators viewed by a photomultiplier tube. Mechanical slat collimators with a Tantalum shield and different viewing angles of $4^o \times 4^o$ and $6^o \times 6^o$ are placed above the detectors. The effective area of each detector is 100 cm^2 with an average energy resolution of 18%@60 keV. Third detector consists of three CZT detector modules of 16 cm^2 each and one CMOS detector with a 4.5cm^2 area. A coded mask is used for the CZT detectors and Fresnel zone plates over the CMOS detector to provide the imaging capability.

The satellite was launched into polar Low Earth Orbit of 550 km on 30th January 2009 from Plesetsk Cosmodrome, Russia. and data analysis is in progress.

2.2.4 *IR satellite*

A small satellite mission for Infra Red Spectroscopic Imaging Survey is currently in the Phase B. It is planned to survey a large fraction of the sky in the 1-6 micron wave band with a spectral resolution of $\sim$ 100. The payload will give a complete catalog of the low mass objects in the solar neighbourhood apart from the study of the interstellar medium and the star forming regions in our galaxy and nearby galaxies. Details of proposed payload and the mission are discussed elsewhere in this volume.

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I am thankful to the organizers of the ISM workshop for their invitation to speak on the subject. I take this opportunity to thank all my colleagues in the academic, scientific and technical branches, with whom I have worked or interacted over the last four and half decades. Since this is a personal account of the growth of space astronomy in India, the material presented is selective and references to the material presented in this paper can be found in the publications of high altitude studies/space astronomy group of TIFR.