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X-RAY ASTRONOMY EXPERIMENT ON THE INDIAN SATELLITE IRS-P3

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ABSTRACT

An x-ray astronomy experiment consisting of three collimated proportional counters and an X-ray Sky Monitor (XSM) was flown aboard the Indian Satellite IRS-P3 launched on March 21, 1996 from SHAR range in India. The Satellite is in a circular orbit of 830 km altitude with an orbital inclination of 98° and has three axis stabilized pointing capability. Each pointed-mode Proportional Counter (PPC) is a multilayer, multianode unit filled with P-10 gas (90% Ar + 10% CH_4) at 800 torr and having an aluminized mylar window of 25 micron thickness. The three PPCs are identical and have a field of view of $2° \times 2°$ defined by silver coated aluminium honeycomb collimators. The total effective area of the three PPCs is about 1200 cm^2. The PPCs are sensitive in 2-20 keV band. The XSM consists of a pin-hole of 1 cm^2 area placed 16 cm above the anode plane of a 32 cm$\times$ 32 cm position sensitive proportional counter sensitive in 3-8 keV interval. The position of the x-ray events is determined by charge division technique using nichrome wires as anodes. The principal objective of this experiment is to carry out timing studies of x-ray pulsars, x-ray binaries and other rapidly varying x-ray sources. The XSM will be used to detect transient x-ray sources and monitor intensity of bright x-ray binaries. Observations of black-hole binary Cyg X-1 and few other binary sources were carried out in early May and July-August 1996 period. Details of the x-ray detector characteristics are presented and preliminary results from the observations are discussed.

I. INTRODUCTION

Time variation of intensity is one of the main characteristics of x-ray sources. Except supernova remnants and clusters of galaxies, nearly all classes of x-ray sources, both galactic and extragalactic, exhibit variability. The variations, both periodic and non-periodic, occur on time scales ranging from sub-seconds in black-hole binaries and pulsars to days, months and longer in other classes of objects. Detailed studies of the variability and its time scale provides important information about the nature of the sources. The x-ray pulsars show regular changes in intensity and are believed to be rotating neutron stars accreting matter from a companion star. By studying changes in the rotation period of the neutron stars with time, one can learn a lot about the accretion process occurring in the neutron stars. Similarly studies of irregular and sporadic intensity changes in black hole binaries and extragalactic sources like Active Galactic Nuclei (AGNs), provides knowledge of the environment of the x-ray emitting regions. X-ray 'photometry' is thus an important tool to advance knowledge of astrophysical phenomena in x-ray binaries and other variable x-ray objects.

Transient x-ray sources are quite a common occurrence in the x-ray sky. Study of the light curves of these 'x-ray novae' and their spectral evolution is important to gain insight into their nature. An X-ray Sky Monitor, which can detect and measure the intensity of transient sources and other known bright objects, is thus an important instrument for any space-based x-ray mission. The Indian x-ray astronomy experiment was designed with these objectives in mind.

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II. DESCRIPTION OF THE X-RAY INSTRUMENT

The Indian x-ray astronomy experiment has two components. One is a set of three collimated proportional counters which are coaligned and used for pointed-mode studies of individual x-ray sources. The second part of the x-ray experiment is an X-ray Sky Monitor (XSM) which is based on the principle of X-ray pin-hole camera and is used for monitoring intensity of transient and other known bright sources. In what follows, we describe the two instruments briefly :

(a) Pointed-Mode Proportional Counters (PPCs)

There are three identical multilayer multianode proportional counters. There are three layers in each detector, each layer containing 18 anode cells with a cross-sectional area of 1.1 cm$\times$1.1 cm and uses a gold-coated stainless steel anode wire of 25 micron diameter and 33.6 cm length. Each anode is surrounded by a cathode wire-wall with wire spacing of 0.275 cm. The anodes of the end cells in each layer and those of the bottom layer are connected together to form a veto or anti layer. The alternate anodes of each layer are also connected together and operated in mutual anticoincidence. Further, the top two layers are also operated in mutual anticoincidence. This arrangement of mutual anticoincidence results in a very significant reduction in the background produced by cosmic ray interactions as well as that due to compton interactions of gamma-rays. A 25 micron thick uncoated polypropylene film is sandwiched between the collimator and mylar entrance window to prevent damage to mylar film due to imperfections on the bottom surface of the collimator. The entrance window is a 25 micron thick aluminised mylar film. An aluminised mylar film of 6 micron thickness is also placed at the top of the collimator for thermal control.

Each PPC is equipped with a honeycomb type collimator having a field of view (FOV) of $2°\times2°$. The collimator is made from 0.15 mm thick aluminium coated with a 6 micron thick layer of silver. The collimator is mounted in the detector housing and the assembly is made leak tight by sandwiching the mylar film against viton O-ring on one side of 1 mm indium O-ring on the opposite side.

There are 5 outputs from each PPC (two each from the first two layers and one from the veto layer). The associated front-end electronics like the charge sensitive pre-amplifiers (CSPA), high voltage DC/DC converter, the high voltage distribution and filter circuits, are mounted on the back side of the detector body to reduce the noise in the CSPA as well as minimise electromagnetic interference. The gain stability of the detector and the front end electronics is monitored on-board by permanently shining the veto layer with a highly collimated Cd109 radio-active X-ray source which emits 22 keV x-rays. The effective area of each PPC is about 400 cm2.

The average detection efficiency is about 50% below 10 keV and drops off rapidly at higher energies, being about 10% at 20 keV. The energy resolution of the PPCs is typically 20% at 5.9 keV. Long term tests in vacuum showed stable performance of the detectors with no significant change in gas gain or resolution.

(b) The X-ray Sky Monitor

The X-ray Sky Monitor (XSM) consists of a pin hole of 1 cm^2 area placed 16 cm above the anode plane of a one dimensional Position Sensitive Proportional Counter (PSPC) of size 32 cm × 32 cm. The PSPC has two anode layers, the front one having 32 resistive nichrome wires of 25 micron diameter serving as the x-ray detection layer and the second one with gold coated stainless steel wire, as the veto layer. Principle of charge division is used to measure the position of each detected x-ray along the anode length. The typical position resolution is about 5 mm, enough to determine position of an x-ray source in sky to an accuracy of about 1° or better. The FOV of XSM is 90° × 90°. Its entrance window is an aluminised mylar of 50 micron thickness. Its sensitivity is limited to 3-8 keV band. The PSPC is also filled with 90% Ar - 10% CH-4 gas mixture. The detector housing is so designed that while the anode frame is housed in the upper part of the housing, the lower part is used for mounting HV supply and distribution network, the charge sensitive preamplifiers, the logic circuits and the pulse height and position measuring circuits. The XSM after HV potting, has a weight of about 11 kg.

(c) The Front End and Signal Processing Electronics and Memory

Each PPC is made modular to facilitate easy replacement. It has an independent HV supply unit, five CSPAs, signal processing electronics and an ADC. The processing and data handling electronics consists of comparators, pulse height discriminators, pulse anticoincidence logic, ID generator, pulse digitiser, broad band programmable pulse counters, power interfaces, telemetry interfaces and telecommand interfaces. The heart of the processing electronics system is a CMOS 16-bit microprocessor (80C86-8) with program and data memories. The processing electronics design is made modular with identical processing and memory units for each PPC. The processing electronics of the PPC is designed to simultaneously measure the intensity and spectral information in the energy range 2-30 keV with programmable integration times. The veto layer, in addition to providing anti coincidence to the two main layers, is also used to monitor gas gain stability and resolution of the PPCs by measuring the energy spectrum of 22 keV X-ray from a collimated Cd109 source mounted on the rear side of the PPC. Each processing module can be operated in different modes with the help of commands.

A 4 megabit memory is used with each PPC processor for in-orbit storage of data. Count rates with selectable integration time are used for the two detection layers and The veto layer to measure the x-ray intensities in 2-6 keV and 2-18 keV bands. A 64 channel ADC based analyser is used for pulse height analysis of accepted x-ray events. A pulse height histogram is built from the analysed events with selectable integration times.

III. LAUNCH, ORBIT AND POINTING

The x-ray astronomy experiment on board the IRS-P3 satellite was launched using Polar Satellite Launch Vehicle (PSLV) on March 21, 1996 from SHAR range in India. The satellite is placed in a 830 km circular polar orbit of 98° inclination and is orbiting the earth with a period of 102 minutes.

The PPC and XSM are mounted on the top deck of the satellite. The view axes of the PPCs are aligned with the roll of axis of the satellite while the viewing axis of the XSM is offset by 35 in the roll-pitch plane. A CCD-based star tracker, capable of detecting stars of upto 6th magnitude, is mounted parallel to the view axes of the PPCs. The IRS-P3 is a three axes stabilized spacecraft and can be pointed towards any source if at least two stars of 6th magnitude or brighter are in the $6°\times8°$ FOV of the star sensor.

The in-orbit performance check of the x-ray instrument was carried out during May 1 - May 9, 1996 period by pointing the PPCs towards the bright x-ray source Cyg X-1. All the three PPCs and the XSM are performing normally. Due to the polar orbit of IRS-P3, most

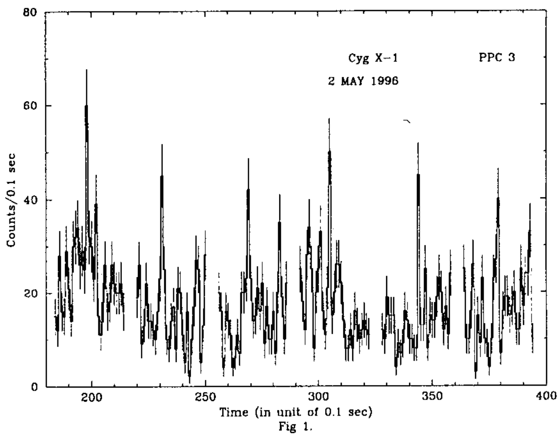

Fig. 1.— The 2-18 keV light curve of Cyg X-1 in 100 msec bins. Variability on time scale of 100 msec is easily discernible.

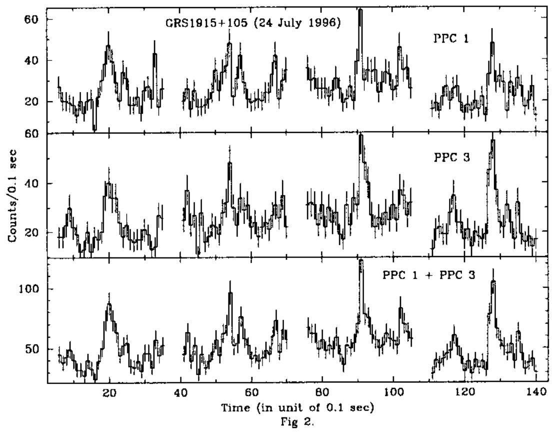

Fig. 2.— Light curve of the superluminal x-ray source GRS 1915+105 with count rates binned in 100 msec bins.

of the orbits pass through the high intensity charged particle zone known as the South Atlantic Anamoly (SAA). Charged particle fluxes are also very high beyond latitude —b— 50°. The x-ray detectors are operated only outside the SAA zones and when —b— $< 50°$ to prevent damage to the detectors. This is achieved by lowering of HV supplied to the detectors by using time tagged commands. Due to these constraints the duty cycle of useful observations is limited to about 15%.

The summed background rate of the 3 PPCs in 2-18 keV region is about 45 counts per second while looking at the source free regions of the sky.

IV. OBSERVATIONS OF X-RAY SOURCES

After successful completion of instrument performance checks during May 1-9, 1996, observation of four more x-ray sources, all being binaries or pulsars, have been carried out so far. These objects are Cyg X-1, GRS1915+105, GX 1+4 and 4U1907+09. The preliminary results are detailed below.

(a) Black Hole Binary Cyg X-1

This was observed during May 1-9, 1996 when it was in a low state and again during July 4-9, 1996 after it made a transition to the bright state. The summed count rate of the three PPCs for Cyg X-1 in 2-18 keV band is about ~500 counts per sec during May 1-9 which increased to a value of about ~1000 counters per sec in July 1996. To study rapid variability of Cyg X-1, reported in the literature (Rothschild et al 1974), the observations were made in 1 sec, 100 msec and 10 msec integration modes. Rapid intensity variations on time scale of 1 sec and 100 msec are clearly seen in the light curve shown in Fig. 1. Preliminary analysis shows that while Cyg X-1 shows pronounced variability on time scale of 100 ms and longer, the variations are not as strong on time scale of 10 ms. Presence of QPOs at a frequency of 0.22 Hz is also discernible in one of the observations.

(b) X-ray Pulsar GX 1+4

This 121 sec pulsar, which has a hard spectrum and large rate of change of period (Rao et al 1994), was observed from July 10-18 period. It was clearly detected as a bright object at a count rate of about 100 counts per sec. Pulse period analysis showed lack of x-ray pulsations, the upper limit to the pulse fraction being less than 5%. To verify that this is genuine and not due to any instrument or analysis related anamoly, we observed the 437 period x-ray pulsar 4U1907+09 during August 5-10, 1996. The x-ray pulsations were clearly seen in this source. Lack of pulsations in GX 1+4, if real as appears highly likely, is a highly puzzling phenomenon not anticipated in accreting binary models, when the source is in a bright state.

(c) Black Hole Source GRS 1915+105

This black hole candidate which also shows superluminal motion (Castro-Rirado et al 1992), was observed during July 20 - August 1, 1996. Its light curve shown in Fig. 2 shows striking resemblance to Cyg X-1 as shown by flaring and burst activity. Variations on time scale of 1 s and less are quite pronounced in this object also. Detailed timing analysis of this object is in progress.

(d) XSM Observations

The in-orbit performance of XSM is satisfactory but observations from it are severely affected due to SAA and high particle zones. The XSM operates, both in the pointed stellar mode as well as in the earth observation mode of the two remote sensing payloads on the IRS-P3 satellite. Analysis of data from XSM is in progress.

V. CONCLUSIONS

The X-ray astronomy experiment on the IRS-P3 satellite is functioning normally. Preliminary analysis of observations from a few x-ray sources shows that it has enough sensitivity for time variability studies of a variety of x-ray sources down to a level of about 1 UFU. Observations of many more sources are planned in the coming months. This experiment, expected to last for at least 2-3 years, should yield valuable data on the periodic and aperiodic intensity changes in x-ray emission from a variety of objects.

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