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First results from the Indian x-ray astronomy satellite

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1. Introduction

An X-ray astronomy instrument consisting of three Pointed Proportional Counters (PPC) and one X-ray Sky Monitor (XSM), was flown onboard the Indian Satellite IRS-P3 (see left panel of figure 1) on March 21, 1996 using a PSLV rocket. The principal objective of this experiment is to carry out variability studies of X-ray binaries and other variable cosmic X-ray sources. The instrument has been functioning satisfactorily since its launch and we have studied periodic and aperiodic variabilities of several stellar X-ray sources. These include blackhole binary Cyg X-1, superluminal source GRS 1915+105 and several X-ray pulsars. Highlights of the results obtained from the observations with the PPCs are presented here.

2. The Pointed-mode Proportional Counters (PPCs)

Each PPC is a multi-anode, multi-layer detector with 54 anode cells of size 11mm × 11mm arranged in 3 layers with a wall-less geometry. The end cells of each layer and the bottom layer are joined together to form a veto layer. Signals from alternate cells of the first and second layers and the veto layer are operated in mutual anti-coincidence to reduce the non X-ray background. The PPCs have an energy range of 2-18 keV with 65% efficiency at 6 keV. A gas mixture of 90% argon and 10% methane is used in the detectors. The typical energy resolution of a PPC averaged over the entire detector is 22% at 6 keV. A sandwich of 25 μ thick aluminised mylar film and a 25 μ thick polyproplyne film serves as the entrance window. Total photon collecting area of the three detectors is 1200 cm^2 and the field of view is 2.3° × 2.3° (see Agrawal et al. 1996a for details of the PPCs).

Light curves in two energy bands can be obtained by operating the detectors in different modes with different integration times ranging from 10 ms to 10 s, and 64 channel pulse height can be obtained with different integration times ranging from 1 s to 1000 s. In a high time resolution mode of operation, arrival time of each photon is noted with 0.4 ms accuracy with 8 channel energy information. The high voltage supplied to anodes is adjustable in small steps which is used to control the gas gain of the detectors. The gas gain of the detectors are continuously monitored by shining one anode of the veto layer with 22.2 keV X-rays from a Cadmium-109 radioactive source.

A CCD based star tracker with a FOV of 6° x 8° mounted on the top deck with its view axis coaligned with that of the three PPCs is used for stellar pointing. The PPCs can be pointed towards a given source only if its angular separation from the sun is > 90°. The satellite is in a circular orbit at an altitude of 830 km and inclination of 98° with the equator. The polar orbit has a severe drawback from the view point of useful observation time. The detectors are usually operated only in –30° to +50° latitude range outside the South Atlantic Anomaly (SAA) region. The PPCs are operated by time tagged commands in this latitude band for about half of the orbits which have limited exposure to SAA region and usually 15 to 20 minutes of useful data is obtained per orbit.

3. Results

The Crab Nebula, a standard calibration source, was observed during 1996 November 29 to December 3. The angular response of the PPCs was measured by slowly scanning along two perpendicular directions with respect to the viewing axis. The observed response of each PPC as measured from the count rate versus time profiles during the scan are plotted for both the scans and shown in figure 1.

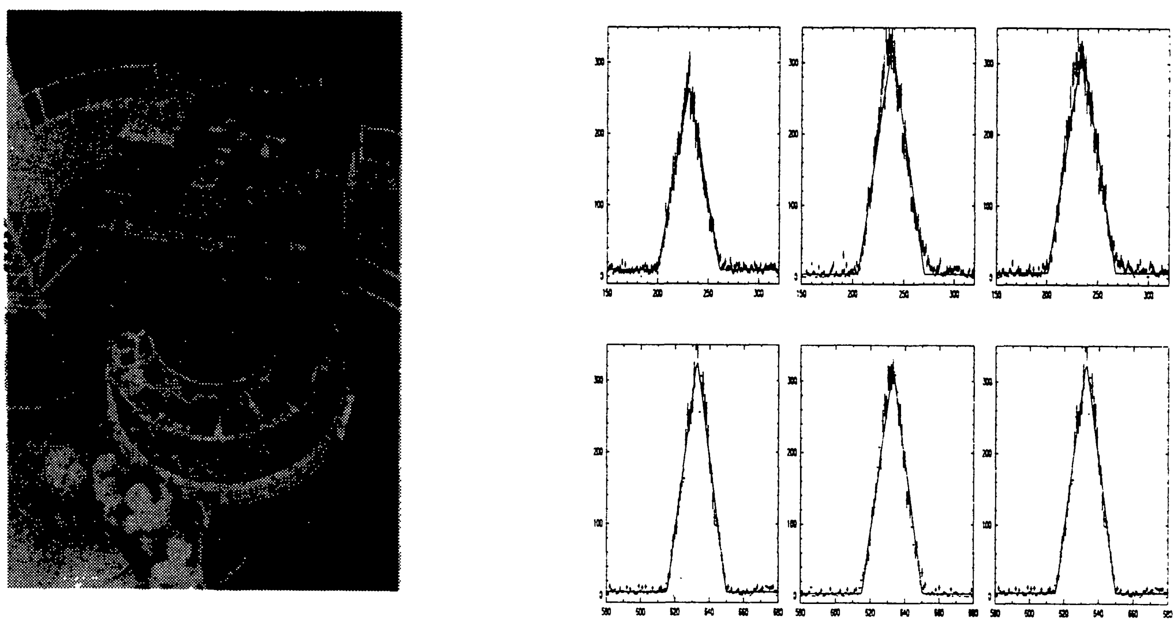

Figure 1. Photograph of the IRS-P3 satellite with the IXAE detectors mounted on the top deck of the satellite and angular response of three PPCs to the Crab Nebula as obtained from scan along two perpendicular directions with respect to the viewing axis.

Performance verification of the instruments were made soon after launch. In about 30 weeks of time available for stellar pointing observation with the IXAE since its launch in 1996 March, many stellar sources including black hole candidates, X-ray pulsars and low mass neutron star binaries were observed successfully with the PPCs. Here we briefly describe some of the important results that have been obtained from the observations made with the PPCs.

3.1 GRS 1915+105

This is a recently discovered transient source that shows strong variability on time scales of days and months in hard X-rays (Castro-Tirado et al., 1994). It is also a flaring radio source and the first one in our galaxy in which superluminally moving radio jets have been detected (Mirabel & Rodriguez 1994). We have made observations of this source on several occasions. Useful exposure was obtained during 1996 July 20-29 for about 9000 s, 1997 June 12-29 for about 40000 s and again during 1997 August for about 15000 s. Observations were made with a time resolution of 0.1 s or 1 s.

In the 1996 July observations, strong and persistent intensity variations over time scale of 0.1 s to a few seconds are clearly detected in the light curves in all the 3 PPCs. Power density spectrum shows a strong peak at a frequency of about 0.7 Hz indicating the presence of quasi-periodic oscillations (QPOs) in the source (Agrawal et al., 1996b; Paul et al., 1997, 1998b). The QPOs are detected independently in each PPC at the same frequency. The PDS of each day shows frequency of QPO to be varying in the range of 0.62 to 0.82 Hz from day to day.

During the 1997 observations, the source was in a very bright state. A unique characteristic noted in the light curves is the presence of strong quasi-regular X-rays bursts. Some representative light curves of 500 seconds duration obtained on different days with one of the PPCs are shown in the bottom left column of figure 2. The power density spectra in the frequency range of 0.001 to 5 Hz, obtained from the light curves consisting of these different type of bursts are shown in the right column of the figure. This is the first black hole source where very well structured bursts of different types have been observed. The bursts also have the unique feature of slow rise and fast decay. The spectrum is found to be harder during the burst decay. These features make the bursts in GRS 1915+105 distinct from both the type I and type II X-ray bursts observed in neutron star sources. Rapid decay of these bursts and corresponding hardening of the spectrum are possible evidences of disappearance of material into the black hole event horizon (Paul et al., 1998a). The regular pattern of the bursts can be produced by material influx into the inner disk due to oscillations in a shock front far away from the compact object.

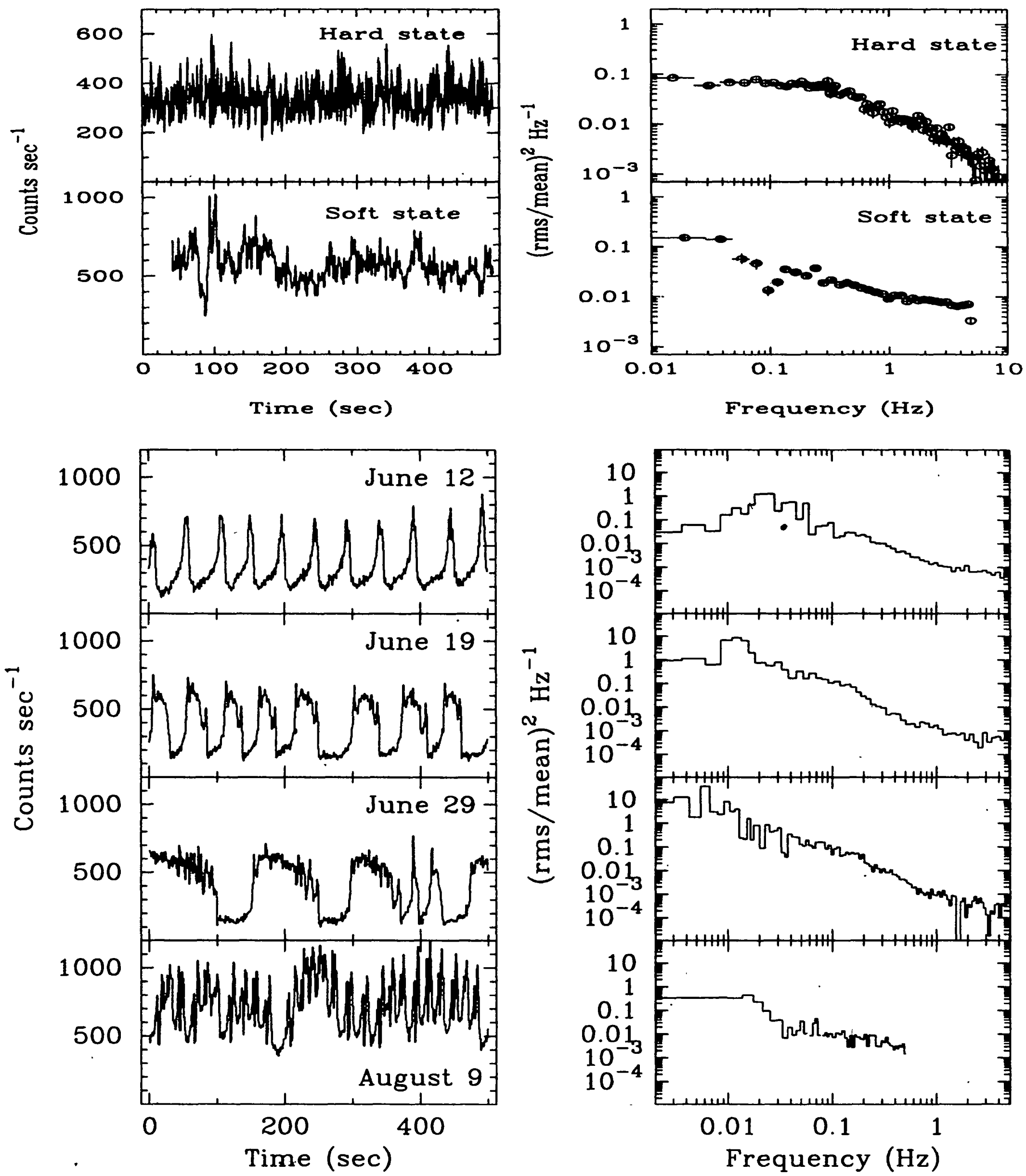

Figure 2. The light curves (left column) and corresponding power density spectra (right column) of two black hole candidates Cygnus X-1 (top) and GRS 1915+105 (bottom) observed with the PPCs.

3.2 Cygnus X-1

The bright X-ray binary Cyg X-1 has a bimodal behaviour with distinct 'soft' and 'hard' states. Rapid and chaotic intensity variations over time scales ranging from milliseconds to days have been observed in this source. Quasi-periodic oscillations have also been detected from it on several occasions. Changes in the power density spectrum (PDS) in this source are found to be associated with change in the spectral state. We made observations of Cyg X-1 with the PPCs during 1996 April 30 to May 11 period in a low-hard state and again during 1996, July 5—8 interval in a soft-bright state.

Random and chaotic intensity variations are seen in both the observations down to time scale of 100 ms which are more pronounced in the low state. Typical light curves in the two intensity states along with the PDS are shown in the top two panels of figure 2. The high state PDS can be fitted by a power law with index of -1.1 between 0.3 to 10 Hz and below 0.3 Hz the PDS is quite flat upto .01 Hz. The PDS for the soft state can also be fitted with a power law of index –0.39 above a frequency of 0.03 Hz indicating that the soft state PDS is flatter compared to the hard state. There is an indication of flattening below 0.03 Hz similar to that seen in the hard state. The present observations confirm that the PDS characteristics are dependent on the intensity state of the source and change smoothly as the source makes transition from one state to another.

The chaotic variability of Cyg X-1 can be analysed in terms of randomly occurring shots of variable duration. The number distribution of the shots in both the states is well described by an exponential function with e-folding time constant of 0.35 s for the hard state and 0.2 s for the soft state (Rao et al., 1997).

3.3 Pulsars

We have detected the 33.4 ms pulsations in the Crab pulsar and also have estimated the energy dependence of the two peaks in the pulse profile (Mukerjee et al., 1998). Pulsations have also been detected in the X-ray pulsars 4U 1907+09, Vela X-1 and GX 1+4. Pulsations observed in Crab and 4U 1907+09 are shown in figure 3.

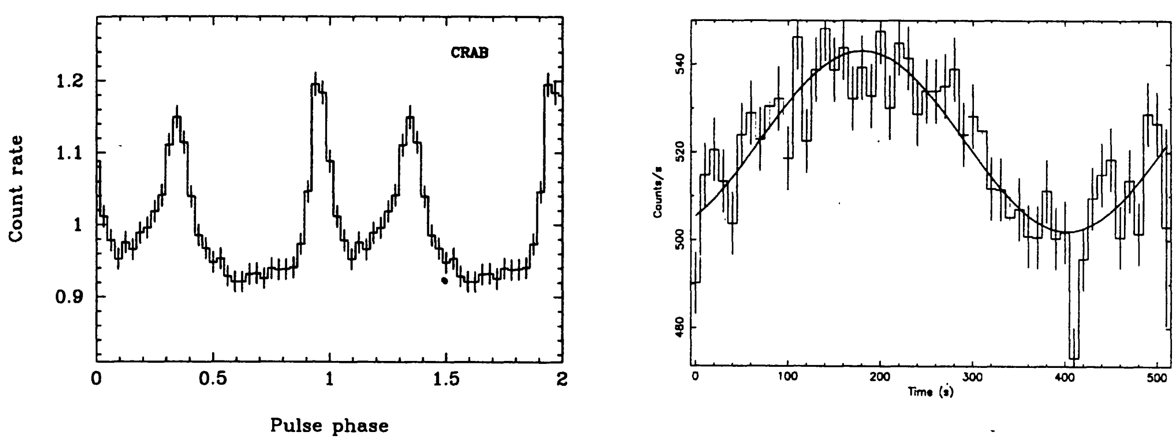

Figure 3. Pulse profiles of the 33 ms X-ray pulsations from the Crab Pulsar and 435 s pulsations from 4U1907+09 observed with the PPCs.

References

Agrawal P. C., Paul B., Rao A. R. et al., 1996a, Journal of Korean Astronomical Society, 29, S429.

Agrawal P. C., Paul B., Rao A. R. et al., 1996b, IAUC No. 6488.

Castro-Tirado A. J., Brandt S., Lund N. et al., 1994, ApJS, 92, 469.

Mirabel I. F., Rodriguez L F., 1994, Nature, 371, 46.

Mukerjee K., Agrawal P. C., Paul B. et al., 1998, BASI, Proceedings of the 18th ASI meeting.

Paul B., Agrawal P. C., Rao A. R. et al., 1998a, ApJ, 492, L63.

Paul B., Agrawal P. C., Rao A. R. et al., 1998b, A&A, Suppl. 128, 145.

Paul B., Agrawal P. C., Rao A. R. et al., 1997, A&A, 320, L37.

Rao A. R., Agrawal P. C., Paul B et al., 1998, A&A, 330, 181.