Bull. Astr. Soc. India (2000) **28**, 281-287

20-200 keV observations of binary X-ray sources with a balloon-borne payload

R.K. Manchanda

Tata Institute of Fundamental Research, Colaba, Bombay 400 005, India

Abstract. The spectral information in the hard X-ray energy region above 30 keV is available only for a small number of X-ray objects even though hard X-ray flux has been observed from about 80 of the 200,000 X-ray sources cataloged so far. We have attempted spectral observations of binary X-ray sources in the 20-200 keV band using a newly developed balloon-borne large area scintillation counter telescope. In this paper we present the hard X-ray spectra of some of these sources obtained during various experiments.

1. Introduction

There is quite a variety of X-ray sources, which emit significant flux in the high energy region. The power emitted in active galactic nuclei shows a ν^{-1} behaviour, thus making these sources as the prime targets for hard X-ray observations. The X-ray flux measurements of the Seyfert galaxies discovered to date, indicate a flat power law spectrum with a power index of 1.4 ± 0.2, and with no steepening even beyond 100 keV. Among the galactic sources Low Mass X-ray Binaries (LMXB) and High Mass X-ray Binary (HMXB) transient X-ray sources show a very hard spectrum. Similarly, the cyclotron line emission observed in various close X-ray binary pulsar lies in the hard X-ray band. The supernova remnants and black hole candidates are the other astronomical objects which emit high energy X-ray photons. Spectral and temporal studies in hard X-ray region can therefore, yield vital information about the relativistic plasma in intense gravitational and magnetic fields and the accretion phenomena. In addition, these also complement the low energy data.

The abundance of low energy data below 6 keV is due to the fact that reflective optics can be used to focus these photons onto a variety of small size detectors. This gives a twin advantage of large concentrating area and extremely low detector background. Secondly, the X-ray photon flux values at lower energies is higher by a factor of $10^3 - 10^4$. Due to the low photon flux levels at energies beyond 30 keV, and the need to use large area detectors with high internal background, the information in the high energy region continues to be spares.

ravi@tifr.res.in

2. Experimental details

In this paper I report the results of hard X-ray survey carried out in the 20-200 keV energy band using a newly developed balloon-borne payload. The observations were made with a Large Area Scintillation counter Experiment (LASE) which is designed to study fast variations in the flux of X-ray sources in the hard X-ray energy region up to 200 keV and is shown in Fig. 1. The payload consists of three large area X-ray detector modules mounted on a servo-controlled platform. The detectors are specially designed combination of thin and thick large area NaI(T1) scintillation counters configured in back-to-back geometry. Each of the detector module has a geometrical area of 400 cm^2 and the thickness of the prime detector is 3mm. The active anti-coincidence shield is provided by a 30 mm thick crystal. The field of view of each modules is $4.5^{\circ} \times 4.0^{\circ}$ and is defined by demountable mechanical slat collimator specially designed with a sandwiched material of Lead, Tin and Copper. Each module along with the collimator is further encased with a passive shield. Each detector is designed as a stand-alone unit with independent on-board subsystems for HV power and data processing. LASE payload is fully automatic with an on-board star tracker and requires no ground control during the flight.

The details of the detector design, associated electronics, control sub-systems and in-flight behaviour of instrument are presented elsewhere (D'Silva et al., 1998)

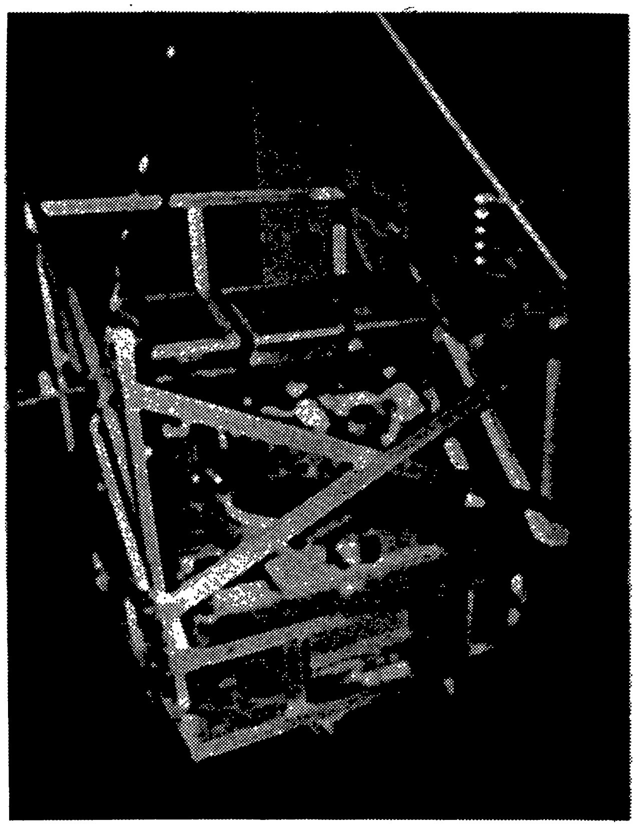

Figure 1. LASE payload assembly.

The scintillation counters give almost an 100% detection efficiency in the operative energy range and the back-to-back geometry gives almost 80% reduction in the detector background, most of which is produced due to partial energy loss by the Compton scattering of high energy photons in the main detector. Successful balloon flights of the payload were carried out from Hyderabad on several occasions. The data present here corresponds to observations made on March 30, 1997.

3. Data analysis and the results

Spectral observations on various X-ray sources were made by pointing the payload to the desired target according to a pre-loaded observations plan. The ambient background was determined by observing a near-by source free region before and after the source pointing. In the case of long exposure for a given source, background was also measured in between the source observation slots. The excess flux due to the sources was then corrected for the detector response and attenuation due to the residual atmosphere including the multiple compton scattering. The response matrix of each detector was constructed from the pre flight calibration of the detectors at different X-ray line energies using a variety of radioactive sources (Am^{241}, Ba^{133}, Cd^{109}). To calibrate the high energy end of chosen energy range, we used highly accurate 'divide by two' attenuaters in the detector outputs and observed the 300 keV and 357 keV lines from Ba^{133}.

3.1 X-ray pulsars

Three X-ray pulsars namely, Her X-1, GR 1744-28 and GS 1843+00 were observed for a period of 40, 70 and 55 min respectively during the flight. The data analysis of GR 1744-28 is still in progress. Apart from establishing the pulse light curve, time averaged spectra were produced for the other two sources.

3.1.1 Her X-1

This neutron star binary X-ray pulsating source was discovered by UHURU in 1972. Source exhibits a variety of temporal features namely, 1.24 sec pulsar, 1.7^d binary orbital period, 1.64^d intensity dips and 35^d on-off cyclic intensity variations in which the source is bright for 11 days and below detection during the 24 day off period. The presence of cyclotron emission features at 58 keV and 100 keV, in the source spectrum were first reported by Trumper et al. (1978). Since its discovery there have been many confirmations of the primary feature but the second harmonic at 110 keV has never been confirmed. It is believed that observation of second harmonic can resolve the emission or absorption of the observed feature.

The time averaged energy spectrum of the source in the energy region 20-200 keV as measured by two detectors is shown in Fig. 2. the error bars represent $\pm 1\sigma$ statistical errors. It is seen from the figure that spectral measurement in the present observations extend up to 180 keV and two absorption features are seen in both the spectra. The observed spectra clearly suggest an underlying power law spectrum. The fitting model therefore, contains 8 parameters consisting of a power law and two Gaussian features in absorption given as;

$$\frac{dN}{dE} = A_1 E^{-A_2} - A_3 e - \left(\frac{E-A_4}{A_5}\right)^2 - A_6 e - \left(\frac{E-A_7}{A_8}\right)^2$$

The power law index was found to be 1.4±0.2 and fitted energy values for the two features are 50 and 108 keV respectively. Even though the individual significance for the second harmonics is low, its presence at twice the energy of the primary feature in two independent detectors enhances its statistical reliability. The present observations correspond to the binary phase $\phi_{1.7}$ = 0.57 and cyclic phase ϕ_{35} = 0.208.

3.1.2 GS1843+00

The transient X-ray pulsar GS 1843+00 with a period of 29.5[8] was in the burst phase during March 1997. The source was observed for 55 minutes in two sightings of 22 and 30 minutes each and an excess of 15000 counts was recorded from the source in 20-180 keV range. The time averaged combined spectrum of the source from both the detectors is shown in Fig. 3. A single power-law fit or a simple exponential energy spectrum does not fit the data. A best fit to the data with a composite power law+exponential function of the form $\frac{dN}{dE} = \frac{A}{E\alpha} e \frac{E-E_c}{kT}\ phcm^{-2}s^{-1}keV^{-1}$ is obtained for A ~ 8.2±2.3 x 10^{-3}, α = 0.76±0.06, E_c ~ 26±2 keV and kT = 72±4 keV. The estimated source luminosity of the source in the 20-200 keV band is 2 x 10^{36} ergs/sec assuming a source distance of 10 kpc.

3.2 Black hole candidates

Two prominent black hole candidates Cyg X-1 and the transient source GRS 1915+105 were also observed during the March experiment. GRS 1915 was in post-burst quiescent phase during the observations. Cyg X-1 was observed only for 30 min period and 70 min pointing was performed on GRS 1915+105 in two sightings of 35 min each.

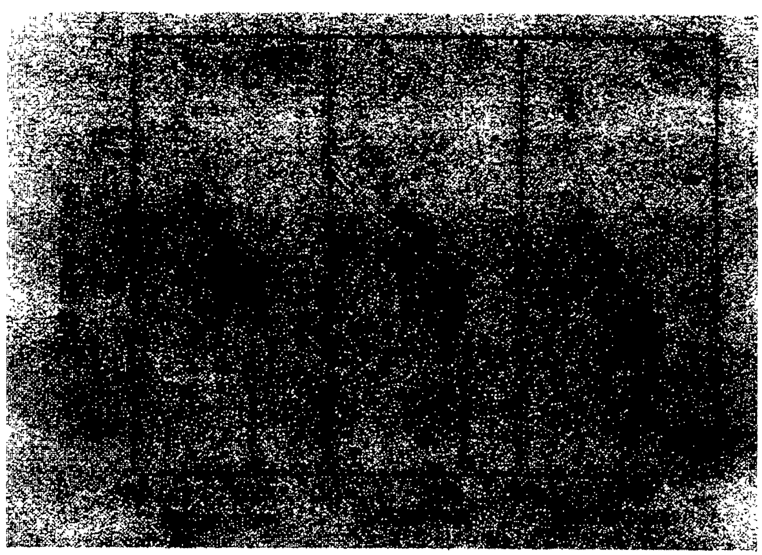

Figure 2. Observed energy spectrum of Her X-1.

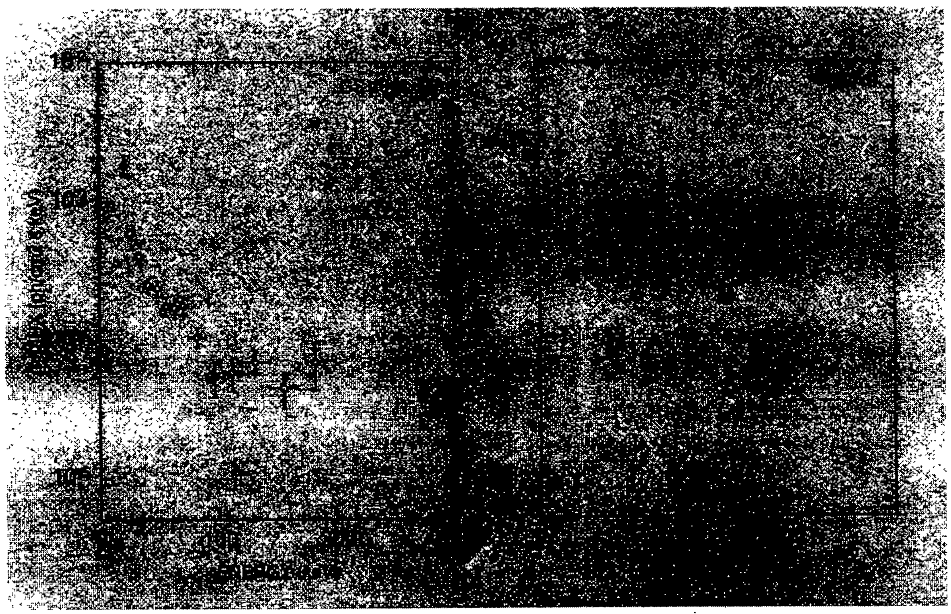

Figure 3. Hard X-ray spectrum of GS 1843+00.

Figure 4. Hard X-ray spectrum of Cyg X-1.

3.2.1 Cyg X-1

Cyg x-1 is the brightest X-ray binary source in the hard X-ray and soft gamma ray energy region to date, and is the best candidate for stellar mass black holes. In spite of extensive studies during the last 35 years, the X-ray source still remains enigmatic. Apart from the 5.8^d binary orbital period the source also exhibits a 300^d periodicity. Intensity variability down to millisec time scales, and chaotic rapid variations have been observed from the source. Spectral variability in hard X-rays on time scales of minutes has been reported from the source. The average behaviour of the source is believed to be two intensity states termed as 'low' and 'high' states, however, HEAO-C observations during september 1979 to July 1980 revealed the presence of a 'super-low' state in which both the soft X-ray and hard X-ray flux drop simultaneously.

X-ray spectrum obtained during the present experiment is shown in the Fig. 4. It is seen from the figure that spectrum is much steeper than the canonical power index α=1.8. The total luminosity of the source was also found to be lower by factor of ~ 10 compared to earlier measurements.

3.2.2. GRS 1915+105

GRS 1915+105 is a transient X-ray source with superluminal radio-jets and is also known as a 'microquasar'. The source became active in 1994 and went into very high intensity state in 1996. The source exhibits several temporal features like the QPO, millisec time variability, a rapid fire flare phenomenon, in regular, quasi-regular and irregular modes. No optical counterpart of this source has been identified so far and hence no data is available on the binary parameters, like the orbital period, mass function etc. The classification of the source to be a black hole candidate is therefore, purely on phenomenological arguments like shape of the flares and a large variety of temporal features.

The hard X-ray spectrum of the source deduced from the combined data of two detectors in the present observations is shown in the Fig. 5. At the time of our observations the source was in a post burst quiescent phase with source luminosity twice the lowest value. It is seen from the figure that X-ray spectrum is very steep and the excess flux extends up to 100 keV. A high energy flux from the source even in the quiescent phase is not surprising as compton tail due to bulk comptonization around the black hole binaries have been suggested in literature.

3.3. Low Mass X-ray Binaries

In the Low Mass X-ray Binaries LMXB, the companion star is usually later than type A or a degenerate star. A late type or degenerate stars do not have strong winds and therefore, the mass accretion on to the compact object takes place through the Roche-lobe. X-ray properties of such objects are therefore, dominated by the accretion disk and its dynamical properties. Among the 32 optically identified LMXB sources, Cyg X-3 is the most prominent and enigmatic member of the group.

3.3.1 Cyg-X3

Low mass X-ray binary Cyg X-3 is a class by itself among all the known X-ray binary sources. The source exhibits 'high' and 'low' intensity states in low energy band. Quasi-periodic oscillation up to 1000 sec, a 4.8 hour modulation interpreted as the orbital period, a possible 16.7^d modulation, possible transient periodicity at 121 sec, escaping radio jets during the intense radio flares and strong IR emission make this source unique.

The source was observed for a total period of 80 minutes and the deduced spectrum is shown in Fig. 6. It is seen from the data that at lower energies up to 60 keV the X-ray spectrum is quite flat and shows a steep drop in intensity above 70 keV. This measurement is consistent

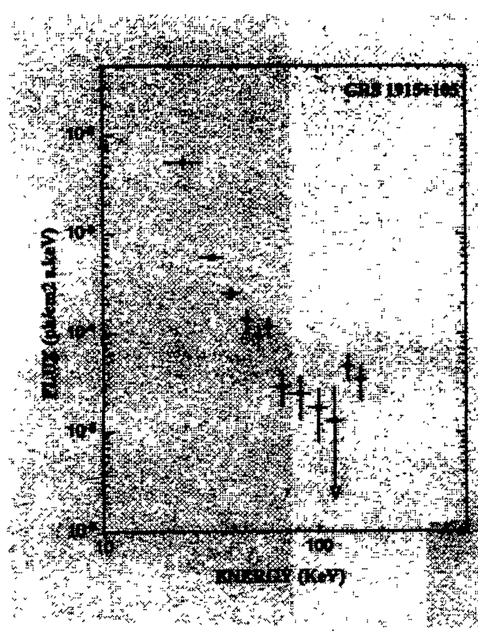

Figure 5. X-ray spectrum of GRS 1915 + 105.

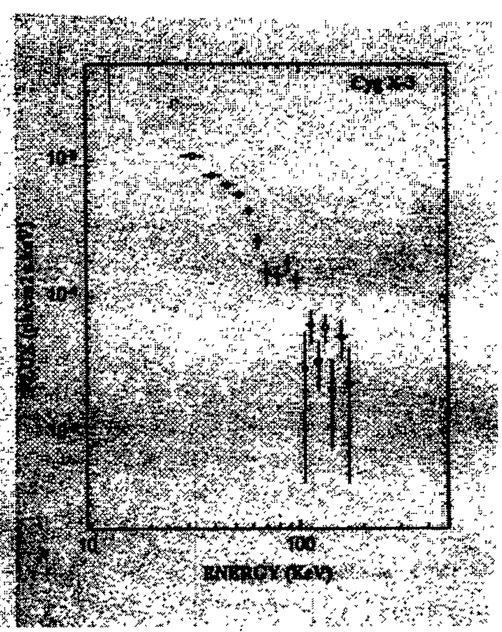

Figure 6. Hard X-ray spectrum of Cyg X-3.

with our earlier data obtained withe xenon counter experiment which gave power law index of $\alpha = 2.8$ in the 20-60 keV region. The drop in the X-ray intensity at higher energies is quite surprising as on occasions, the source has been observed even at gamma ray energies.

Acknowledgements

I thank sarvashri J.A.R. D'Silva, P.P. Madhwani, N.V. Bhagat, B.G. Bagade and Ms. N. Kamble for their support in fabrication of the payload and flight support. I also thank the staff at the TIFR balloon facility, Hyderabad for fabricating the balloon and conducting a successful balloon flight.

References

D'Silva J.A.R., Madhwani P.P., Tembhurne N., Manchanda R.K. 1998, Nucl. Inst. & Meth., A 412, 342.3 mm

Trumper J., Pietsch W., Repin C., Voges W., Staubert R., Kendziorra E., 1978, Astrophys, J., 219, L 109.