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Her X-1 observed in a low state

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Abstract. The X-ray pulsar Her X-1 was observed on 14th December, 1992 with two balloon borne Xenon filled multicell proportional counters (XMPC) from Hyderabad, India. The source intensity was found to be very low in the 20-100 KeV observation range of the detectors. At the time of observation the source was in its main 'on' state of the 35 day cycle. Comparison with the expected count rate in main 'on' state in the pair of detectors gives an observed luminosity about 5 times lower. Because of very low intensity and probably low pulse fraction, pulsation were not seen.

1. Introduction

The X-ray binary Her X-1 was discovered in 1972 with the UHURU satellite (Tananbaum *et al.*, 1972) and is a very well observed object in Hard X-rays because of its high hard luminosity and interesting temporal behaviour at three different time scales. Most unambiguous among these is the 1.7 day orbital period, in which the source shows X-ray eclipse also. It also shows variability over a period of 35 days in which the source is in high luminosity state twice. First one which lasts for about 5 days is called the main 'on' state, and the second one which lasts for about 11 days is called short 'on' state. The long time variability of 35 days is not very well understood and is attributed to various phenomena. Mostly talked are the precession of the twisted disk (Petterson 1975), precision of the neutron star (Trumper *et al.*, 1986) or sometimes even a periodicity in the mass transfer rate from the companion (Crosa & Boynton 1980). The other time scale at which the source shows periodicity is spin period of the neutron star of 1.24 seconds. The neutron star shows pulsations because of its high magnetic field of about 3 to 5 times 10^{12} Gauss which is deduced from the cyclotron lines. The pulse fraction is seen to vary from a very low value to 85% in different phases of the 35 day cycle (Trumper *et al.* 1986; Soong *et al.* 1990). The spin period of the source is found to change over an observation period of 20 years in a complicated fashion. Various satellite and balloon observations established this period change behavior. We made balloon observation of Her X-1 with the high resolution XMPC detectors to make a detail study of the continuum and cyclotron emission or absorption line in the source spectrum. Here we give details of the observation and results of the balloon flight made with the two XMPC detectors.

2. observation

Observations were made on 14th December, 1992 from a balloon flight made from Hyderabad, India with two Xenon filled Multicell proportional counters (XMPC). The set of two detectors, identical in design, with area 1200cm^2 each, have three layers of proportional counter cells of size 48 x 48cm^2 along with one veto layer on the three sides. The detection efficiency is about 50% in the 20-100 keV range. Field of view is restricted to 5° x 5° by a passive tin copper collimator. The set of detectors have overall energy resolution of 13% at 22 keV. The detectors operate in escape gating mode to increase the ratio of detection efficiency to background rejection efficiency. Time resolution of the quick look data (QLD) is 2.56 ms and that of spectrally analyzed data is 82 ms. For XMPC details see Rao *et al.*, 1991. The balloon was launched at 00.10 UT on December 14th and reached ceiling at 02.30 UT and was at the float altitude of 39 kms till 11.30 UT. The vertical air mass during the observation was in the range 3.1 to 3.6 gmcm^{-2}. The duration of observation for the source and the source-free background regions 7° away from the source, were 10,800 and 4,500 seconds respectively. Source and a source-free background region tracked alternately for 30 and 10 minutes, respectively.

3. Analysis and results

To measure the pointing accuracy during the flight, aspect calibration was done three times with Cyg X-1, by going off from the source –5° to +5° in azimuth firsh and then same in elevation. From this source triangulation the pointing accuracy was measured and was found to be 0.3° in elevation and about 2° in azimuth. But at an elevation angle of 60° the actual inaccuracy is about 20% in the 5° x 5° field of view detectors. A plot of the count rates in the two detectors during the source and background observations is given in figure 1. The source counts in the 20 - 100 keV range as seen in the plot is $0.86 \pm 0.21 s^{-1}$ in DET-A and $1.01 \pm 0.17 s^{-1}$ in DET-B. During the whole observation of Her X-1 the background was found to be reasonably constant in both the detectors. Periodogram was made near the Her X-1 pulsation period 1.24 sec from both the on source and off source observation sets. In the periodogram of source counts broad peaks in different period values were seen but none with much significance. The periodogram of background observations also gave broad peaks of comparable heights in the period range 1.235 s to 1.245 s. This is possibly because of very large number of (64,000) unevenly timed data points. Analysis was done with simulated data having poisonian noise on a constant count rate with the same time distribution. Similar broad peaks of comparable heights were seen in the simulated data. This establishes the absence or undetectability of pulsation in the source. The same period analysis technic was used for detecting pulsations in GX 1 + 4 observed on other occasion with the same X-ray telescope (Rao *et al.*, 1994).

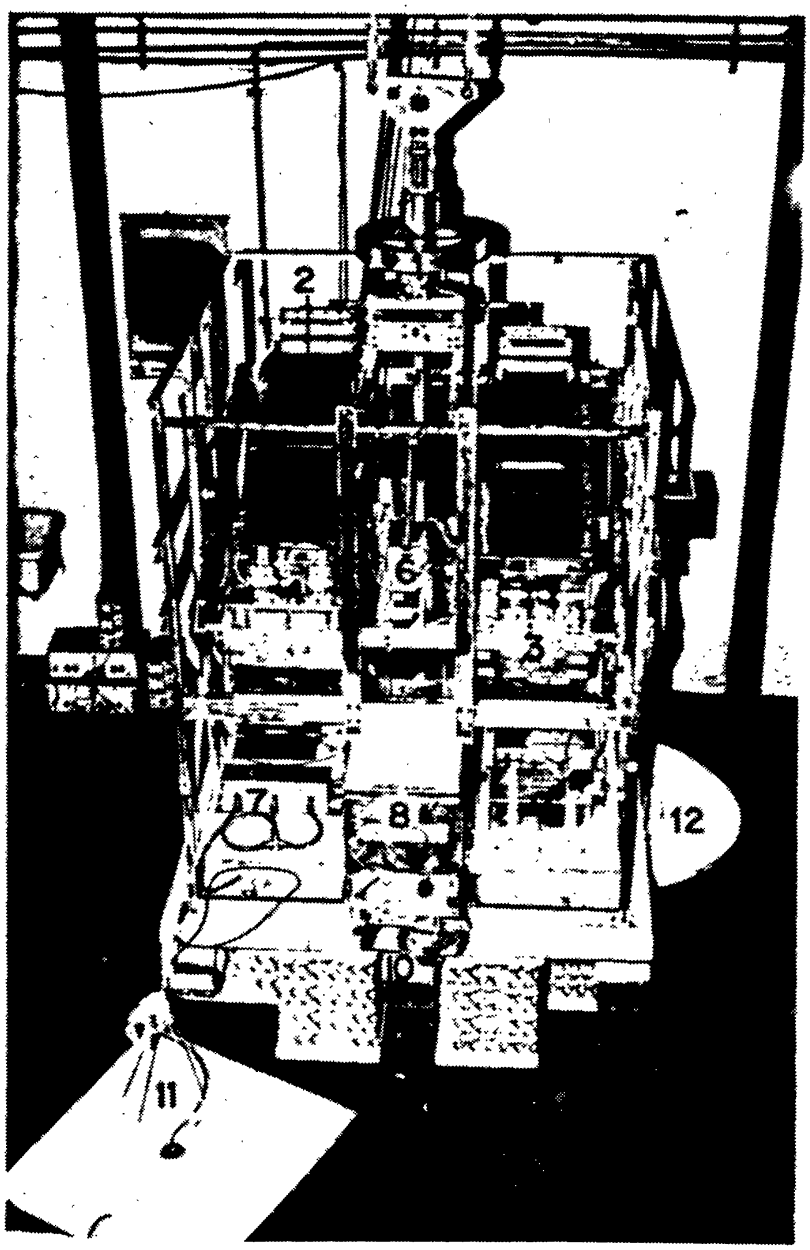

Figure 1: Photograph of the X-ray Telescope. Various subsystems are marked with numbers as follows: 1. reaction wheel, 2. collimator, 3. detector, 4. high voltage DC/DC converter, 5. high voltage distribution box, 6. calibration source, 7. baratron, 8. M. F. beacon, 9. batteries, 10. crash pad, 11. telemetry transmitter antenna, 12. telemetry receiver antenna.

Figure 1.

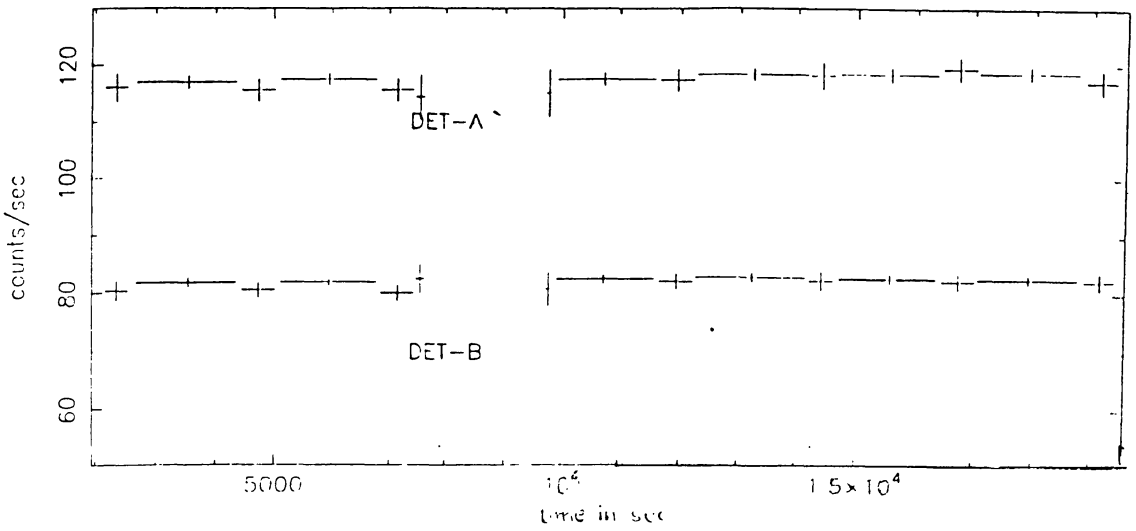

Figure 2. Count rate profile of Her X-1 as observed on 14 December, 1992. Two profiles are for two detectors with background count rates 120 and 85 per second respectively. The energy range is 20-100 keV. Alternate points are for background and source observations.

The detector response was obtained using Monte Carlo simulation. The energy resolution and gain in individual proportional counter cells were determined by shining the detectors with different redioactive X-ray sources. The residual air mass effect, window transmission and escape of fluroscence X-rays from the active volume were taken into account for making the response matrix (Chitnis 1994). For Her X-1 in main 'on' state the hard X-ray spectrum is described by an exponential with cyclotron line in emission or absorption. If the cyclotron line is an emission line, it has an energy of about 48 keV with FWHM of about 10 keV. If it is an absorption line, the energy is somewhat lower, about 35 keV with FWHM of 8.5 keV (Tueller *et al.* 1984, Voges *et al.* 1982). However Voges *et al.* have got a much thinner absorption line at the same energy with FWHM of 3 keV. The cyclotron lines observed in the source spectrum indicate the presence of a strong magnetic field of strength 3 to 5 x 10^{12} Gauss. The expected count rate in the detectors are $5.4s^{-1}$ respectively when an incident spectrum with exponential cutoff at energy 6.7 keV and cyclotron emission line at 48 keV with FWHM of 10 keV is taken with the norms as described by Tueller *et al.* This is obtained by taking the model spectra and convolving that with the calculated detector response. The detection efficiency and the response matrix of the detectors is found to give luminosity of a

source from its observed spectra upto inaccuracy of less than 1% in case of Cyg X-1, an observation of which was made in the same balloon flight.

4. Discussion

The balloon borne detectors observed Her X-1 in 1992 at a much lower flux level than what is expected in the main 'on' state. Long time study of the onset of main 'on' states has established that two successive main on states always start at an interval of 20.5 ± 0.5 times its orbital period (Staubert *et al.* 1982). An WATCH observation saw the onset of main on state just two cycles before, on 30 Sept-01 Oct., 1992 (Brandt 1994), from which we conclude that during our observation also the source was in main on state. ROSAT and ASCA observations of the source made in August 1993 also observed the source in a much lower intensity level (Vrtilek *et al.* 1994). However their observation in the energy range 0.1 keV to 35 keV the observed flux is about 10 to 50 times lower than the expected flux. So we assume that in this unusual low state of the source the spectrum has hardened. ASCA observations gave 3σ upper limit on the amplitude of pulsation to be 1.5%. At such low pulsation level detection of pulsation in high energy is not possible.

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