Search for pulsations in the low mass X-ray binary Sco X-1

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Sco X-1 is the brightest X-ray binary below 20 keV. Hard X-ray tails have been reported from the source on various occasions. The source is categorized as the Z-source since the source intensity traces a Z-shape in the colour-colour diagram. The source also exhibits strong QPO's in the 2-25 Hz band along with the kilo-hertz QPO discovered in recent data. No positive detection of a pulse period has been made so far. This paper reports the results of the balloon-borne hard X-ray observations carried out using LASE payload specifically configured to search for pulsation in the hard X-ray band.

1. Introduction

Sco X-1 is a prototype for the low mass X-ray binary systems in which accretion proceeds by the mass transfer from the primary to the compact companion through the Roche lobe overflow. It is the brightest persistent X-ray source in the sky below 20 keV with a orbital period of 0.787 days X-ray flux modulation at this orbital period is not seen to date. Below 20 keV. The X-ray source is a low magnetic field accreting matter from its low mass companion with estimated mass of 0.42 $M_\odot$ [1]. The distance of the source is estimated to be 2.8±0.3 kpc [2]. No coherent pulsations have been seen from the source so far. A 2.93 msec pulsation was reported by Damle et al. [3], however this period has not been confirmed to this date by any other experiment [4].

With a radio morphology of a compact core and relativistic jets, Sco X-1 shows a quasar like behaviour. However, in terms of the energetics and its X-ray beaviour, compared to other quasars it can be termed as nano quasar [5]. Sco X-1 shows three characteristic luminosity states namely, quiescent, active (intensity increase $\sim 50\%$) and flaring (increase by $\sim 2 - 4$). The intensity variations in ScoX-1 trace a Z shape pattern in the X-ray colour-colour diagram [6]. The source exhibits strong QPOs at low energies in the quiescent state and the power density spectrum shows a large power in the 2-25 Hz band with a strong peak at ~ 6 Hz. The QPO behaviour is bi-model in nature, where the 6 Hz power is anticorrelated with the source intensity, the 10-20 Hz power is strongly correlated with intensity during the active phase [7]. The QPOs frequency increases with the source brightness in an irregular manner and at the brightest levels of the source, the QPOs disappear completely [8]. Kilo Hertz quasi periodic oscillations in Sco X-1 were discovered from the RXTE data [9]. The kHz QPOs are mainly observed in pairs with in the frequency range up to 1300 Hz, and have also been seen in 20 other LMXB systems [10]. No positive detection of QPOs in the hard X-ray data above 30 keV has been made so far. The absence of QPO at high energies is significant, as it suggest a complete decoupling of the low energy photons and the hard X-ray tails, since the physical models involving thermal emission can not explain the observations.

2. Data

The data were obtained in the balloon flights launched in Nov 1998, April 1999 and Nov 2003 from Hyderabad, India, using Large Area Scintillation counter Experiment (LASE). The instrument described in detail by [11], is designed to make observations in the 20-200 keV energy band. The detection system comprises of three modules of scintillation detectors with a total area of 1200 cm^2 having both passive and active shielding and

fitted on a fully steerable alt-azimuth mount. Each of the detector module is specially configured combination of thick and thin crystal of NaI(Tl) in a back-to-back geometry for low background. The field of view of each modules is $4.5^o \times 4.5^o$ and is defined by a graded collimator effective up to 250 keV. LASE payload is fully automatic with an on-board star tracker and requires no ground control during the flight. The attitude of the telescope is controlled by a microprocessor using 12 bit absolute optical shaft-encoders allowing a stability better than 0.1^o during the source observation. During the flight, the gain stability of the detectors is monitored with Am^{241} radioactive source, using ground command. The 3σ sensitivity of the LASE telescope in the entire energy range up to 200 keV is $\sim 1 \times 10^{-6}cm^{-2}s^{-1}keV^{-1}$ for a source observation of 10^4 sec. During the first two flights, the source was tracked for 60 minutes in two intervals of 30 min each, interspersed between background measurements before, after and in-between. During the recent observation in 2003, source was tracked for a continuously for 60 minutes to provide long data for period analysis.

The arrival time of each accepted photon is recorded with an accuracy of 25 microsec. In the earlier experiment in 1998 and 1999, the time tagging was with reference to the start of the telemetry frame. During our data analysis, we discovered that since data formatting was done using an onboard microprocessors, which introduced a delay of few microsec between the frames. Therefore, the 2003 experiment was specially configured to look for periodic components in Sco X-1 and a new OCXO controlled clock was developed to provide an absolute time tag for each accepted photons with an accuracy of 25 microsec.

All observations corresponded to the quiescent state of the source as determined from the ASM data on board RXTE. The spectral analysis was carried out from the observations made in 1998 and 1999. Hard X-ray tails were seen in both the data. The source excess counts were corrected for the atmospheric absorption, window transmission, detection efficiency and the energy resolution of each detector using the inverse matrix generated from the calibration data as described in [12]. The entire data up to 185 keV during each flight can not be fitted to a either a single power law or an exponential thermal bremsstrahlung spectrum. The best fit to the data was obtained by a combined fit consisting of two components namely; thermal bremsstrahlung and a power-law describing the hard X-ray tail.

$$F(E) = A(E/30keV)^{-1-\alpha}e^{-(E-30)/kT} + BE^{-\gamma} \quad \text{ph. cm}^{-2}\text{s}^{-1}\text{keV}^{-1} \quad \text{where;} \quad \alpha = 0.37(30/\text{kT})^{0.15}$$

represents the Gaunt factor correction [13]. The best-fit temperature kT varied from 4 keV to 5.2 keV between two observations however, the power law component had the same value of the spectral index $\alpha \simeq 0.7$., thereby suggesting the absence of any generic connection of the hard tails with the low energy photons [5].

PERIODIC COMPONENTS

For the search of periodic components we have used the data from 1999 and the 2003 LASE flights. We computed the arrival time of each photon and searched for the coherent pulsed emission around 3 msec as reported in literature using XRONOS folding routine. To look for the high frequency Quasi-periodic oscillations in our data, we rebinned the data with 0.5 msec resolution and reanalyzed the observed photons using FTOOLS.

1999 Data

In the case of April 99 data we restricted the search to up to 50 keV to increase the signal to noise ration. The folded data is shown in figure The data is shown in Fig. 1 (lower panel). It is seen from the figure that there is no statistical significant peak around the reported pulsar period of 2.92 msec. A small increase in the power is seen at the nearby period of 2.7 msec but similar enhancement is seen even at higher period 4.5 msec. The power density spectrum is shown in the Fig. 1 (upper panel). It is clear from the figure that there is no evidence of any dominant frequency in our data in the 1-1000 Hz range during quiescent luminosity state.
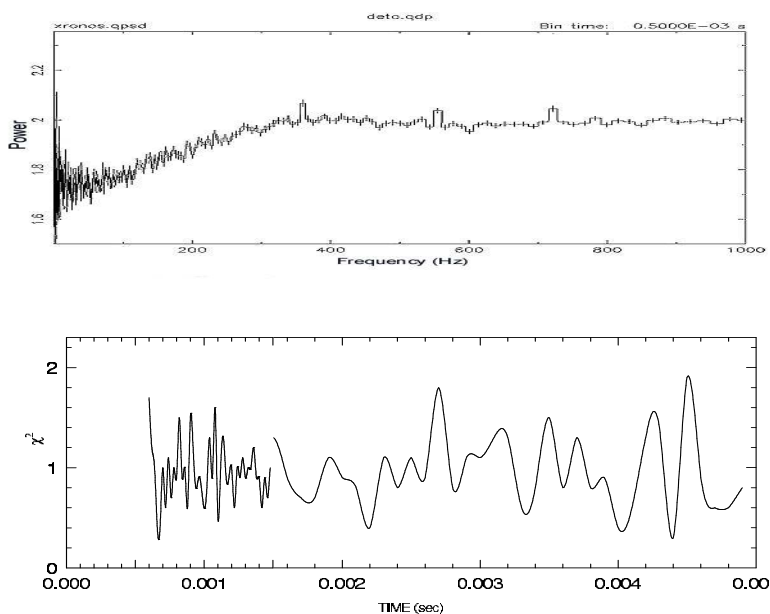
Figure 1. *upper* Power density spectrum using FTOOLS *bottom* Period search in the time tagged data near 2.9 msec

2.1   2003 Data

As mentioned above the source observations were specially configured to search for coherent period in Sco X-1. We have tabulated the absolute arrival time of the accepted photons along with the PHA value of the event. A fast-folding routine based on the method given by Horne-Baliunas [14] was used to find the period in the period range of 0.5 to 120 msec. The preliminary analysis of the time tagged data for each of the three detectors is shown in the figure 2. The data was searched in the 30 to 80 keV energy band, The plot gives the maximum deviation in any of the phase bin for a given trial period. It is seen from the figure that no significant peak is seen in any of the distribution.

In conclusion, Sco X-1 does show variable temporal nature. No coherent period was detected in our data at around 2.7 msec in any of our data. The search for the quasi periodic oscillations and long term periods in the 2003 data is in progress.

3.   Acknowledgements

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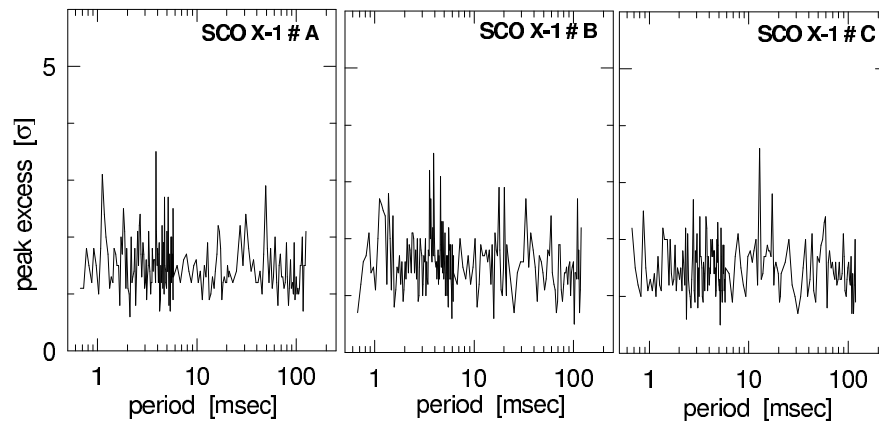[1] D. Steeghs D., & J. Casares J.,, ApJ, 568, 273 (2002).

Figure 2. Maximum deviation in any phase bin for a given trial period in three detectors.

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