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Spectral Analysis of the Low-Mass X-Ray Binary 4U 1728–34 Using AstroSat/SXT Observations

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Abstract
We present a spectral study of the neutron star low-mass X-ray binary (LMXB) 4U 1728-34 using archival observations obtained with the Soft X-ray Telescope (SXT) onboard AstroSat. The analysis was carried out using the Level-2 cleaned event files retrieved from the AstroSat Support Cell archive. Standard data reduction procedures were performed with the HEASOFT software package, while spectral fitting was carried out using XSPEC version 12. The source spectrum was analyzed over the 7.0–7.0 keV energy range using an absorbed power-law model (TBabs × powerlaw) to investigate the continuum emission properties.

The best-fitting model yields a hydrogen column density (N_H) of $(3.07 \pm 0.086) \times 10^{22}$ cm^{-2} and a photon index (Γ) of 1.73 ± 0.03. The spectral fit resulted in a chi-square value of 92.54 for 94 degrees of freedom, corresponding to a reduced chi-square of 0.98 and a null hypothesis probability of 52.3%, indicating acceptable fit agreement between the model and the observed spectrum. The residuals show no significant systematic deviations, suggesting that the absorbed power-law model provides an adequate description of the source emission within the selected energy range.

The obtained spectral parameters are consistent with the hard (island) spectral state commonly observed in Atoll-type neutron star low-mass X-ray binaries, where the X-ray emission is primarily dominated by Comptonized radiation from a hot electron corona. The present study demonstrates the capability of AstroSat/SXT for investigating the spectral properties of accreting neutron star systems and provides a useful foundation for future broadband spectral studies combining observations from multiple AstroSat instruments.

Keywords: AstroSat, Soft X-ray Telescope (SXT), X-ray binaries, Neutron stars, Spectral analysis. XSPEC, 4U 1728–34

1.Introduction

Low-mass X-Ray Binaries (LMXBs) are binary star systems consisting of a compact object, either a neutron star or a black hole, and a low-mass companion star (typically <1-2 MΘ). Matter is transferred from the companion star through Roche-lobe overflow, forming an accretion disk around the compact object. As the material spirals inward, gravitational potential energy is converted into thermal and non-thermal radiation, producing intense X-ray emission. Because of their extreme physical conditions, LMXBs provide an excellent laboratory for studying accretion physics, plasma interactions, strong gravity, and radiation mechanisms (Frank et al., 2002; Lewin & van der Klis, 2006).

Neutron star LMXBs are commonly classified into Z sources and Atoll sources according to their spectral and timing behavior observed in X-ray color–color and hardness–intensity diagrams (Hasinger & van Klis, 1989). Atoll sources exhibit transitions between the hard (island) and soft (Banana) spectral states, which are primarily governed by changes in the mass accretion rate. These state transitions are accompanied by significant variations in both spectral and timing properties, providing valuable insight into the structure of the accretion disk and the Comptonizing corona (Done et al., 2007).

About the source: 4U1728–34

The Galactic X-ray source 4U 1728–34, also known as GX 354–0, is a persistent neutron star low-mass X-ray binary located toward the Galactic bulge. The source was first reported in the Fourth Uhuru X-ray Catalog (Forman et al., 1978) and is one of the best-studied Atoll sources. The source is well known for exhibiting frequent thermonuclear Type-I X-ray bursts, burst oscillations, and kilohertz quasi-periodic oscillations (kHz QPOs), indicating the presence of a weakly magnetized neutron star (Lewin et al., 1993; van Straaten et al., 2001; Di Salvo et al., 2000). Observations with RXTE, XMM-Newton, NuSTAR, and AstroSat have revealed strong spectral and timing variability over different accretion states, making 4U 1728–34 an important target for investigating neutron star accretion processes and high-energy emission mechanisms.

AstroSat, launched by the Indian Space Research Organisation (ISRO) on 28 September 2015, is India’s first dedicated multi-wavelength space observatory (Singh et al., 2017). The mission carries five scientific payloads that enable simultaneous observations from the ultraviolet to hard X-ray energy bands. Among these instruments, the Soft X-ray Telescope (SXT) operates over the 0.3–8.0 keV energy range and employs grazing-incidence Wolter-I optics coupled with a CCD detector (Singh et al., 2016). The SXT provides imaging and moderate-resolution spectroscopy, making it well suited for investigating the spectral properties of compact X-ray sources such as neutron star and black hole X-ray binaries.

In the present work, archival AstroSat/SXT observations of 4U 1728–34 are analyzed to investigate the soft X-ray spectral properties of the source. Standard data reduction procedures and spectral fitting techniques are employed using HEASOFT and XSPEC to determine the continuum spectral parameters and examine the dominant emission processes during the observation.

2. Observations and data reduction

The archival observation of 4U 1728–34 used in this work was obtained from the AstroSat Support Cell (ASSC) archive maintained by the Indian Space Science Data Centre (ISSDC). The spectral analysis was carried out using the Level-2 (L2) processed data products obtained from the Soft X-ray Telescope (SXT) onboard AstroSat. Since the Level-2 data products are generated using the standard SXT pipeline, they are already calibrated and screened for scientific analysis. The observation details used in the present study are summarized in Table 1.

Table 1. observation details

Parameter	Description
Source Name	4U 1728–34
Observatory	AstroSat
Instrument	Soft X-ray Telescope (SXT)
Observation ID	A05_229T04_9000002890
Observation Date	4 May 2019
Exposure Time	10.69 ks
Data Level	Level-2 (L2)
HEASOFT Version	Version 6.33.2
XSPEC Version	XSPEC v12
Energy Range Used	0.7 – 7.0 keV

The downloaded Level-2 event files from individual satellite orbits were first merged using the sxtEventMerge task of the AstroSat SXT data analysis software to produce a single event file for the complete observation. The standard SXT pipeline performs calibration and screening procedures, including event screening, gain correction, bad-pixel removal, charge transfer efficiency (CTE) correction, and detector response calibration, ensuring that the data products are suitable for scientific analysis (Singh et al., 2016).

The merged event file was analyzed using the HEASOFT software package through the XSELECT environment. Source events were extracted from a circular region of 15 arcmin radius centered on the source position, while the background spectrum was extracted from a nearby source-free region. The extracted source spectrum was subsequently grouped using the grppha task with a minimum of 15 counts per spectral bin, thereby improving the statistical quality of the spectrum and allowing the use of χ^2 statistics during spectral fitting.

The Ancillary Response File (ARF) was generated using the sxtARFModule task, while the appropriate Redistribution Matrix File (RMF) corresponding to the observation was obtained from the AstroSat SXT calibration database. The grouped spectrum, together with the corresponding RMF and ARF files, was loaded into XSPEC version 12 for spectral analysis. The spectral fitting was performed over the 0.7–7.0 keV energy range, where the calibration and response of the SXT instrument are well established. The best-fitting model parameters were determined using χ^2 minimization techniques (Arnaud, 1996; Singh et al., 2016; Singh et al.,2017).

3.Spectral Analysis

3.1 Extracted SXT Spectrum

The extracted source spectrum of 4U 1728–34 obtained from the AstroSat/SXT observation is shown in Figure 1. The spectrum was generated from the merged Level-2 event file after applying the standard SXT data reduction procedures described in the previous section. Source photons were extracted from a circular region of 15 arcmin radius. While the background spectrum was obtained from a nearby source-free region. The extracted spectrum represents the distribution of detected X-ray photons as a function of detector channel and forms the basis for subsequent spectral modelling.

The extracted spectrum exhibits statistically significant source counts over a wide range of detector channels, confirming that the observation has sufficient photon statistics for reliable spectral analysis. The count distribution is concentrated mainly in the low- and intermediate-energy channels and gradually decreases toward higher channels, which is consistent with the typical spectral response of the AstroSat/SXT instrument for bright neutron star low-mass X-ray binaries. Before spectral fitting, the extracted spectrum was grouped using the grppha task with a minimum of 15 counts per spectral bin. Spectral grouping improves the statistical quality of the data by increasing the number of counts in each bin and ensures that the χ^2 minimization technique can be applied reliably during model fitting.

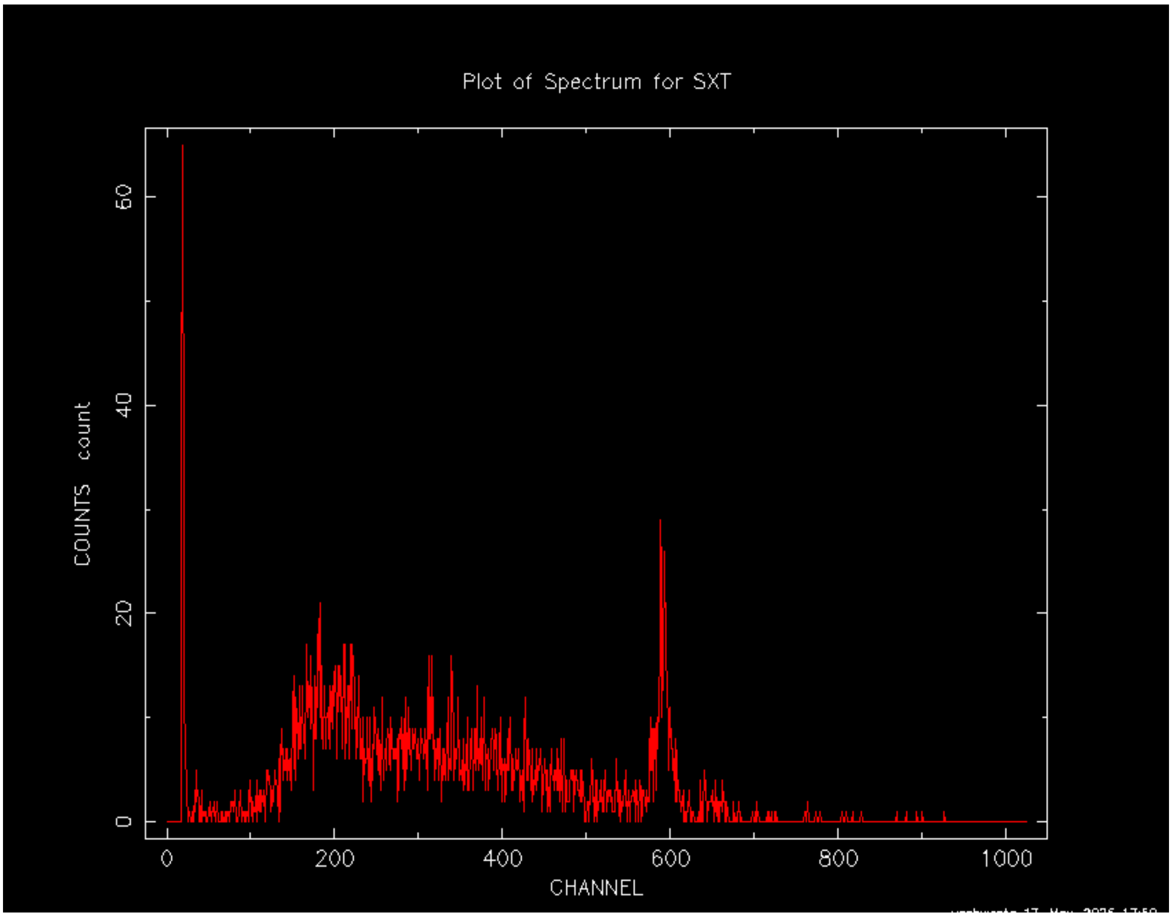

Figure 1. Extracted source spectrum of 4U 1728–34 obtained from the AstroSat/SXT observation before spectral fitting.

3.2 Spectral Modeling and Fitting

The grouped spectrum was analyzed using the XSPEC version 12 spectral fitting package (Arnaud, 1996). The corresponding Redistribution Matrix File (RMF) and Ancillary Response File (ARF) were applied to account for the detector response, effective area, and energy redistribution of the SXT instrument. Spectral fitting was performed over the 0.7–7.0 keV energy range, where the calibration of the instrument is well established (Singh et al., 2016; Singh et al., 2017).

To model the observed X-ray continuum, the absorbed power-law model TBabs × powerlaw was adopted. In this model, TBabs describes the photoelectric absorption caused by interstellar material along the line of sight and is parameterized by the equivalent hydrogen column density (NH), whereas the powerlaw component represents the intrinsic non-thermal X-ray emission from the source. In neutron star low-mass X-ray binaries, such non-thermal emission is generally attributed to the Comptonization of low-energy seed photons by a hot electron corona surrounding the compact object.

The mathematical form of the adopted spectral model can be expressed as

$$F(E) = \text{TBabs}\,(N_H) \times KE^{-\Gamma}$$

Where F(E) is the observed photon flux at energy E, N_H is the equivalent hydrogen column density, K is the power-law normalization, and Γ is the photon index. The parameter N_H characterizes the amount of interstellar absorption, while the photon index determines the slope of the X-ray continuum. Lower values of Γ correspond to a harder spectrum, whereas higher values indicate a softer spectrum.

The best-fit model parameters were obtained using the χ^2 minimization technique, and the uncertainties quoted in this work correspond to the 90% confidence level for a signal parameter. The resulting best-fit spectral parameters are summarized in table 2.

Table 2. Best-fit Spectral Parameters of 4U 1728–34

Parameter	**Best-fit value**
Hydrogen Column Density (N_H)	$(3.072 \pm 0.086) \times 10^{22}$ cm^{-2}
Photon Index (Γ)	1.726
Power-law Normalization	0.576 ± 0.017
χ^2	92.54
Degree of freedom	94
Reduced χ^2	0.98
Null Hypothesis Probability	52.3%

The spectral fitting yielded a hydrogen column density of $N_H = (3.072 \pm 0.086) \times 10^{22}$ cm^{-2} and a photon index of $\Gamma = 1.726$, indicating a relatively hard X-ray spectrum. The reduced χ^2 value of 0.98 for 94 degrees of freedom, together with a null hypothesis probability of 52.3% demonstrate that the adopted model provides an excellent statistical description of the observed data.

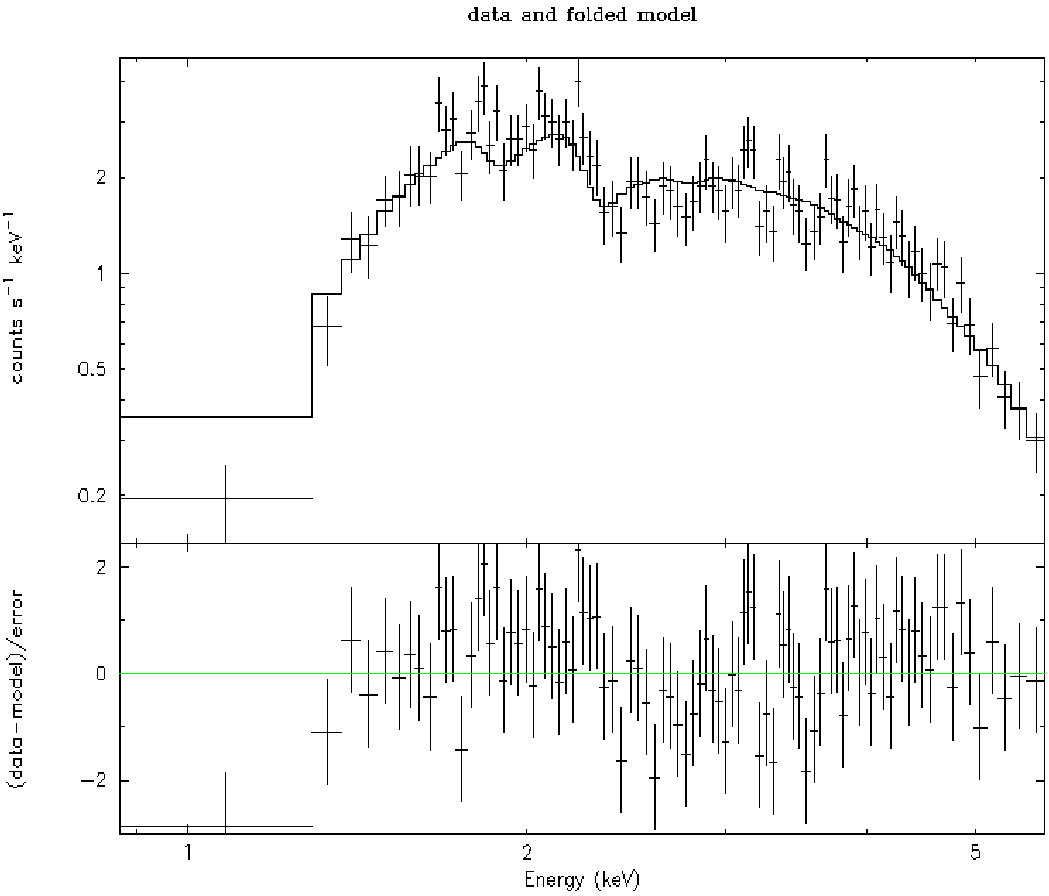

Figure 2. Folded AstroSat/SXT spectrum of 4U 1728–34 fitted with the TBabs × powerlaw model over the 0.7–7.0 keV energy range. The lower panel shows the delchi residuals between the observed data and the best-fitting model.

The folded spectrum together with the best-fitting model is presented in Figure 2. The upper panel shows the observed spectrum and the fitted TBabs × powerlaw model, while the lower panel displays the residuals (delchi) between the observed data and the best-fitting model. The residuals are randomly distributed around zero without any significant systematic deviations, indicating that the adopted model adequately reproduces the observed spectrum within the selected energy range. No statistically significant additional spectral component was required to obtain an acceptable fit.

4.Result and Discussion

The spectral analysis of 4U 1728–34 demonstrate that the observed X-ray spectrum is well described by an absorbed power-law model (TBabs × powerlaw) over the 0.7–7.0 keV energy range. The best-fitting model yielded a hydrogen column density of $N_H = (3.072 \pm 0.086) \times 10^{22}$ cm^{-2} and a photon index of Γ = 1.726, with a reduced χ^2 of 0.98 for 94 degrees of freedom. The null hypothesis probability of 52.3% indicates that the adopted model provides a good statistical representation of the observed spectrum.

The derived hydrogen column density is consistent with the significant interstellar absorption expected toward the Galactic bulge and agrees well with previously reported values for 4U 1728–34 obtained from earlier X-ray missions. The measured photon index (Γ = 1.73) corresponds to a relatively hard X-ray continuum and is consistent with the hard (island) spectral state commonly observed in Atoll-type neutron star low-mass X-ray binaries. In this spectral state, the X-ray emission is primarily dominated by non-thermal radiation produced through Comptonization of soft seed photons by energetic electron in a hot corona surrounding the neutron star.

The folded spectrum and the corresponding residuals demonstrate that the adopted spectral model successfully reproduces the observed data over the selected energy range. The residuals are randomly distributed around zero without any significant systematic deviations, indicating that the absorbed power-law model adequately describes the continuum emission. Furthermore, no statistically significant improvement in the fit was obtained by introducing an additional thermal component, suggesting that the non-thermal continuum dominates the observed X-ray emission during the present observation.

The spectral parameters obtained in this work are broadly consistent with previous studies of 4U 1728–34 using RXTE, XMM-Newton, NuSTAR, and other X-ray observations, which have reported similar hard-state spectral characteristics for this source (Di Salvo et al., 2000; Van Straaten et al., 2001; Basu et al., 2022). The present results therefore support the interpretation that 4U 1728–34 was observed in a hard accretion state during the AstroSat observation.

The obtained photon index (Γ=1.73) is consistence with a relatively hard spectral state observed in Atoll neutron star systems. The successful description of the spectrum by a single absorbed power-law model suggest that the continuum emission is dominated by Comptonized radiation during the present observation. Future broadband studies combining AstroSat/SXT with LAXPC and CZTI observations will help constrain the physical properties of the corona and the accretion geometry in greater detail.

5.Conclusion

In the present work, archival observations of the neutron star low-mass X-ray binary 4U 1728–34 obtained with the Soft X-ray Telescope (SXT) onboard AstroSat were analyzed using the standard HEASOFT and XSPEC data analysis package. The spectral analysis was performed over the 0.7–7.0 keV energy range using the absorbed power-law TBabs × powerlaw.

The best-fitting spectral parameters yielded a hydrogen column density of $N_H = (3.072 \pm 0.086) \times 10^{22}$ cm^{-2} and a photon index of $\Gamma = 1.726$. The obtained reduced χ^2 value of 0.98 and the null hypothesis probility of 52.3% confirm that the adopted model provides an excellent description of the observed X-ray spectrum.

The measured photon index is consistence with a relatively hard (island) spectral state, where the X-ray emission is predominantly governed by non-thermal Comptonized radiation from a hot electron corona surrounding the neutron star. The absence of significant systematic residuals further demonstrate that a single absorbed power-law model adequately describes the continuum emission within the analyzed energy range.

The present study highlights the capability of AstroSat/SXT to perform high-quality Soft X-ray spectral studies of neutron star low-mass X-ray binaries. The results presented here provide a useful basis for further broadband investigations combining simultaneous observations from SXT, LAXPC, and CZTI, which will enable a more comprehensive understanding of the accretion geometry, coronal properties, and spectral state evolution of 4U 1728–34.

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