

Probing spectral variability in NGC 4490 ULX-8 over 24 yr of *XMM-Newton*, *Chandra*, and *Swift*-XRT observations

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ABSTRACT

We present a spectral variability study of the ultraluminous X-ray source NGC 4490 ULX-8 based on 14 *Chandra*, 6 *XMM-Newton*, and 19 *Swift*-XRT observations obtained between 2000 and 2024. The X-ray spectra are modelled using absorbed power-law and absorbed multicolour disc blackbody models. The best-fitting photon indices span $\Gamma \simeq 0.9$ –2.7, while the inferred inner disc temperatures lie in the range $kT_{\text{in}} \simeq 1.0$ –1.6 keV. We detect pronounced long-term variability in the unabsorbed X-ray luminosity on multiyear time-scales, while variability within individual observations is comparatively modest. A hardness–intensity Diagram of the source shows no clear transition between hard and soft states; however, two recent observations taken on 2022 December 1 and 2024 May 4 show a sharp increase in brightness. The spectra across all observations are dominated by smooth, single-component curvature in the 0.3–10 keV band, consistent with the broadened-disc regime of ultraluminous X-ray sources. A correlation analysis reveals a weak positive L_X – Γ trend that remains statistically supported after controlling for absorption-related degeneracies, indicating that it is not driven solely by fitting covariance. The L_X – T_{in} relation is only weakly constrained, but remains compatible, within uncertainties, with both thin-disc and slim-disc scalings. Using disc parameters derived from higher quality *XMM-Newton* spectra, we obtain model-dependent estimates of the characteristic inner disc radius and compact-object mass as functions of inclination and spin. The reported results are consistent with a stellar-mass black hole accretor operating at or near the Eddington limit.

Key words: accretion, accretion discs – methods: observational – X-rays: individual: NGC 4490 ULX-8.

1 INTRODUCTION

Ultraluminous X-ray sources (ULXs) are point-like, non-nuclear extragalactic compact objects with isotropic luminosities (L_X) exceeding 10^{39} erg s^{−1} (P. Kaaret, H. Feng & T. P. Roberts 2017; A. King, J.-P. Lasota & M. Middleton 2023), roughly the Eddington limit for a $10 M_\odot$ black hole (BH). ULXs consist of a compact object, either a BH or a neutron star (NS) accreting from a companion star. They were initially hypothesized to host intermediate-mass black holes (IMBHs; 10^2 – $10^5 M_\odot$) accreting at sub-Eddington rates (E. J. M. Colbert & R. F. Mushotzky 1999; J. M. Miller, A. C. Fabian & M. C. Miller 2004), an interpretation invoked to explain ULXs in general and, in particular, the more extreme hyperluminous X-ray sources (HLXs) with luminosities exceeding 10^{41} erg s^{−1} (e.g. N. A. Webb et al. 2010, A. D. A. MacKenzie, T. P. Roberts & D. J. Walton 2023). While HLXs are still widely regarded as strong IMBH candidates, growing evidence favours the interpretation that most ULXs are stellar-

mass BHs or NSs accreting at near- to super-Eddington rates, facilitated by optically thick outflows or geometrical beaming (S. Fabrika et al. 2015). This has been supported by dynamical mass estimates, detection of ULXs hosting stellar-mass BHs (C. Motch et al. 2014; S. Fabrika et al. 2015; R. F. Shen et al. 2015) and the discovery of more than 10 pulsating ULXs (pULXs), definitively indicating NS accretors, such as M82 X-2 (M. Bachetti et al. 2014), NGC 7793 P13 (F. Fürst et al. 2016; G. L. Israel et al. 2017b), NGC 5907 ULX1 (G. L. Israel et al. 2017a), NGC 300 ULX1 (S. Carpano et al. 2018), and NGC 1313 X-2 (R. Sathyaprakash et al. 2019).

NGC 4490 is a late-type spiral galaxy currently interacting with the irregular galaxy NGC 4485. A distance of 7.8 Mpc, based on the Tully–Fisher (TF) relation (R. B. Tully 1988), has been widely adopted in the literature for the system. More recent tip of the red giant branch (TRGB) measurements using *Hubble Space Telescope* (*HST*) data place NGC 4490 at 6.5 Mpc and NGC 4485 at 8.8 Mpc (E. Sabbi et al. 2018). These distances imply a three-dimensional separation of ~ 2.3 Mpc between the galaxies, which is difficult to reconcile with evidence for an ongoing strong tidal interaction (e.g. S. Pearson et al. 2018; Y. Liu et al. 2023). Owing to this inconsistency, several studies have instead adopted

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Table 1. Summary of observations for NGC 4490 ULX-8. Exposure times (in ks), after flare removal, are listed for EPIC-pn/MOS1/MOS2 detectors for *XMM-Newton*, ACIS-S for *Chandra*, and the X-ray Telescope (XRT) for *Swift*.

Mission	Epoch ID	Obs. ID	Date	Exposure (ks)
<i>Chandra</i>	C1	1579	03/11/2000	19.52
	C2	4725	29/07/2004	38.47
	C3	4726	20/11/2004	38.74
	C4	20999	06/11/2018	14.79
	C5	23482	27/11/2020	28.68
	C6	23483	27/12/2020	29.47
	C7	23484	24/01/2021	29.37
	C8	23485	21/02/2021	29.87
	C9	23486	19/03/2021	29.66
	C10	23487	18/04/2021	29.57
	C11	23488	15/05/2021	29.47
	C12	23489	12/06/2021	29.59
	C13	23490	08/07/2021	29.38
	C14	23491	06/08/2021	29.56
<i>XMM-Newton</i>	XM1	0112280201	27/05/2002	10.21/15.37/15.38
	XM2	0556300101	19/05/2008	15.25/18.64/18.64
	XM3	0556300201	22/06/2008	23.66/28.72/28.73
	XM4	0762240201	12/06/2015	7.59/10.04/10.04
	XM5	0824450201	29/12/2018	36.49/55.15/55.23
	XM6	0891020301	30/05/2022	22.71/28.14/17.67
<i>Swift-XRT</i>	S1	00031155001	04/03/2008	4.93
	S2	00031155002	07/03/2008	4.23
	S3	00031155004	12/03/2008	3.13
	S4	00031155006	18/03/2008	4.28
	S5	00031155010	21/03/2008	2.04
	S6	00031155016	07/04/2008	2.21
	S7	00031155017	11/04/2008	1.88
	S8	00031155019	17/04/2008	2.60
	S9	00031155020	18/04/2008	2.36
	S10	00031155021	22/04/2008	5.85
	S11	00031155022	25/04/2008	4.17
	S12	00031155023	26/04/2008	4.35
	S13	00037784001	22/11/2008	13.20
	S14	00085424002	30/11/2014	2.48
	S15	00085424013	31/05/2015	2.44
	S16	00085424014	12/08/2015	3.84
	S17	00089252002	14/06/2022	1.49
	S18	00015121005	01/12/2022	1.52
	S19	00015121012	04/05/2024	1.66

a pair-averaged distance of 7.14 Mpc (G. Theureau et al. 2007). Furthermore, a recent reanalysis of the colour–magnitude diagrams by I. D. Karachentsev & P. Kroupa (2024) indicates that the TRGB location has been determined unreliably for NGC 4490/85. Hence, in this work, we adopt a distance of 7.8 Mpc for NGC 4490 based on the TF relation when computing luminosities in order to maintain direct consistency with previous X-ray studies (T. P. Roberts et al. 2002; J. K. Fridriksson et al. 2008; J. C. Gladstone & T. P. Roberts 2009; T. Yoshida et al. 2010; S. Avdan et al. 2019) of ULXs in this system.

This ongoing interaction of NGC 4490/85 is known to trigger active star formation, at a constant rate of $\sim 4.7 \text{ M}_{\odot} \text{ yr}^{-1}$ (M. S. Clemens, P. Alexander & D. A. Green 1999; M. S. Clemens & P. Alexander 2002), making this system an ideal laboratory for studying ULX populations. This interaction-driven star formation is likely responsible for the development of an extensive neutral hydrogen (HI) envelope encompassing the galaxy. NGC 4490 has been observed multiple times in X-rays, beginning with *ROSAT* (A. M. Read, T. J. Ponman & D. K. Strickland 1997; T. P.

Roberts & R. S. Warwick 2000). T. P. Roberts et al. (2002) studied the C1 *Chandra* observation (see Table 1) to resolve X-ray sources in the galaxy, identifying 6 ULXs and a total of 36 X-ray sources. A. J. Richings et al. (2010) examined the diffuse hot interstellar medium of NGC 4490 and catalogued the discrete X-ray source population using the first three *Chandra* observations (C1–C3). This diffuse soft X-ray emission is also visible in the merged images presented in Fig. 1. We adopt the ULX nomenclature of J. K. Fridriksson et al. (2008), who catalogued 8 ULXs (ULX-1 through ULX-8) and 38 discrete X-ray sources based on C1–C3 and *ROSAT*.

Among NGC 4490’s known ULXs, ULX-8 (CXOU J123043.1+413818; J. K. Fridriksson et al. 2008) is a particularly intriguing candidate for investigating long-term timing and spectral variability. ULX-8 stands out as one of the brightest, along with ULX-3, ULX-4 and ULX-6. Notably, the position of ULX-6 is consistent with the nucleus of NGC 4490, as identified in recent optical and infrared studies by A. Lawrence et al. (2020). ULX-1, 3, and 4 lie in close proximity, complicating

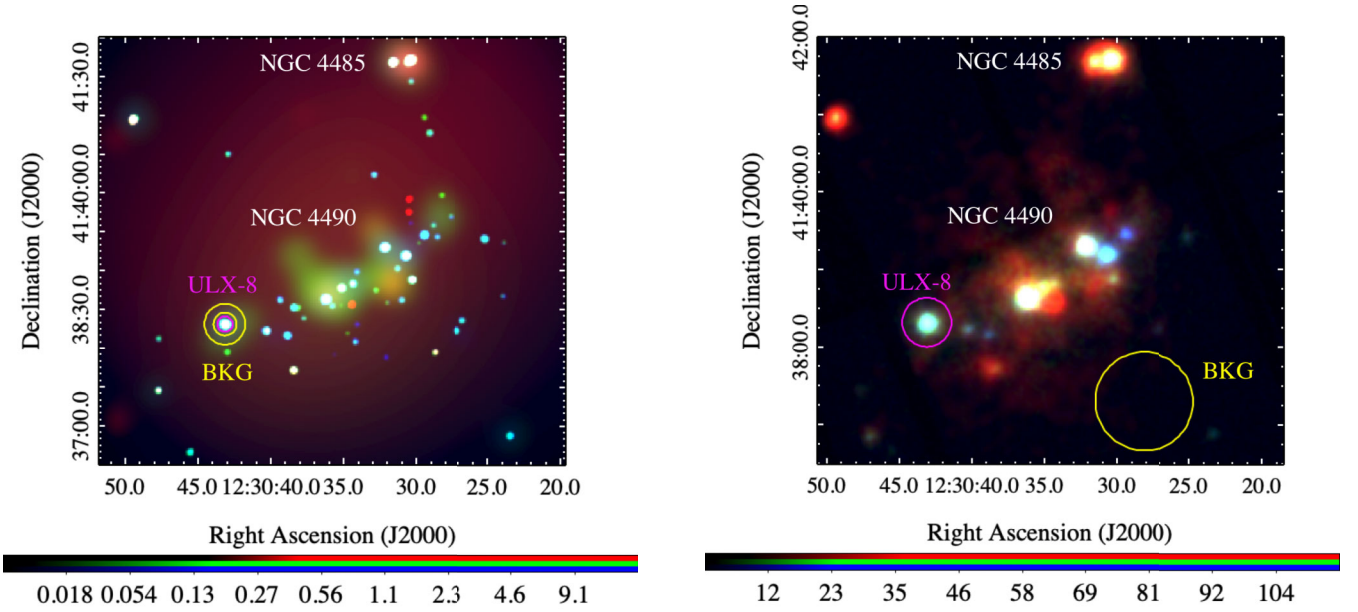


Figure 1. False-colour X-ray images of NGC 4490/85 created from smoothed and merged observations. Representative source and background regions are marked in magenta and yellow colours, respectively. Red corresponds to emission in the 0.3–0.65 keV energy band, green to the 0.65–1.5 keV band, and blue to the 1.5–6.0 keV band. The colour scales are shown below each image. *Left:* Image created from *Chandra* observations. *Right:* Image created from EPIC-pn and MOS1/2 observations with *XMM-Newton*.

their analysis using *XMM-Newton* due to source contamination. Extraction regions for these sources would need to be smaller than 9 arcsec to avoid overlap, limiting the available counts and affecting spectral fidelity. In contrast, ULX-8 is relatively isolated, allowing source extraction from circular regions as large as 19 arcsec in *XMM-Newton*, thereby ensuring high-quality data suitable for long-term spectral and timing analysis. Previous studies of ULX-8 were based on limited data sets: J. C. Gladstone & T. P. Roberts (2009) and T. Yoshida et al. (2010) analysed the *Chandra* C1–3 and *XMM-Newton* XM1 observations (see Table 1). S. Avdan et al. (2019) identified the optical counterparts of ULXs in the NGC 4490/4485 system using archival *HST* imaging, combined with *Chandra* C1–3 and *XMM-Newton* XM1–4 observations, and examined their long-term X-ray variability. Using astrometry, they determined the X-ray position for the source, with coordinates $RA = 12:30:43.180$ and $Dec = +41:38:18.72$. More recently, H. P. Earnshaw et al. (2025) presented results from a *Chandra* Large Programme that monitored 36 ULXs across three nearby galaxies, including NGC 4490, to study long-term variability behaviours.

We present the most extensive investigation of NGC 4490 ULX-8 to date, drawing on the full suite of archival *Chandra* and *XMM-Newton* observations together with 19 *Swift*-XRT data sets. By unifying both analysed epochs (XM1–4, C1–3, C5–14) and several unexplored observations (XM5, XM6, C4, S1–S19), we are able to track the temporal and spectral evolution of ULX-8 across short (intra-observation), intermediate (weeks–months), and long (years) time-scales. Our analysis aims to:

- (i) Track variability in the unabsorbed X-ray luminosity of the source across two decades.
- (ii) Examine potential correlations among key spectral fitting parameters using statistical tools.
- (iii) Assess the physical implications of our findings for the accretion regime and the nature of the compact object.

2 OBSERVATIONS AND DATA REDUCTION

In this work, we study six *XMM-Newton* (F. Jansen et al. 2001), 14 *Chandra* (M. C. Weisskopf 1999), and 19 *Swift*-XRT (D. N. Burrows et al. 2005) archival observations of NGC 4490 ULX-8. In this paper, we label observations as XM1–6, C1–C14, and S1–S19 (Table 1). We have used all available *Chandra* and *XMM-Newton* observations, except for *XMM-Newton* Obs. ID 0891 020 501 and *Chandra* Obs. ID 28115, due to their low post-reduction exposure times. For *Swift*-XRT observations, we have filtered the archival data set for a detection significance above 3σ , leading to 19 observations (Table 1) for further analysis. The corresponding *Swift*-XRT spectral products had sufficient counts, based on count rates and exposure times (see Table 3), to justify the use of C-statistics. Some of these *Swift*-XRT observations, as well as the *Chandra* observation C4, were originally targeted at SN2008ax, a supernova in NGC 4490. However, ULX-8 is detected in these fields and is therefore included in our analysis.

2.1 XMM-Newton

We used Scientific Analysis Software¹ (*sas*) v. 21.0.0 to process all the observations. Standard *emproc* and *epproc* tasks were used to reprocess the Observation Data Files (ODFs) for the MOS and pn detectors, respectively. A filtering constraint of `FLAG == 0` was used for the EPIC cameras. Data were reduced by selecting single to quadruple events (`PATTERN ≤ 12`) and energies within 0.2–12 keV for the MOS detector and by selecting single and double events (`PATTERN ≤ 4`) and energies within 0.2–15 keV for pn. To identify intervals of flaring particle background, we generated single-event (`PATTERN == 0`), high-energy light curves² using

¹<https://www.cosmos.esa.int/web/XMM-Newton>

²<https://www.cosmos.esa.int/web/xmm-newton/sas-thread-epic-filterbackground>

the `evselect` task, choosing energies above 10 keV for MOS and between 10–12 keV for pn detectors. Subsequently, we created a Good Time Interval file, which was used to filter the event files using the same task. While the filtering reduced the effective exposure times for most observations by some margins, it does not impact the reliability of our spectral and timing analyses. We extracted source products from circular regions of radius 19 arcsec centred at ULX-8. The background region was chosen from a circle of radius 38 arcsec on the same charge-coupled device (CCD) as the source region (Fig. 1, right panel). A barycentric correction for timing analysis was performed using the `barycen` task with the known coordinates of the source. We used `evselect` to create source and background products. The `epiclccorr` task was used to generate background-subtracted light curves, applying various absolute and relative corrections. The redistribution matrix file (RMF) and ancillary response file (ARF) were generated using the `rmfgen` and `arfgen` tasks, respectively. These were then grouped with the source and background spectra using the `specgroup` task with a minimum of 20 counts per energy bin to ensure adequate statistics for spectral fitting.

2.2 Chandra

The *Chandra* data were analysed using `ciao` ³ v. 4.15, employing the calibration files (`caldb` ⁴ v. 4.10.4). All the observations were performed with the Advanced CCD Imaging Spectrometer (ACIS) with the aim point placed on the S3 chip of the ACIS-S array. The raw event 1 files were reprocessed and `vfaint` mode was used for observations C2–C4. We restricted the data to the energy range 0.3–10 keV and checked for flares, which did not affect any of the observations. We also confirmed that the ACIS data had source counts below the temperature limit of 164.15 K, in accordance with the ‘Removing Warm ACIS Data’ thread.⁵ ULX-8 is located off-axis in most *Chandra* pointings, where the broader point spread function (PSF) required the use of elliptical extraction regions for source products. These were centred on the source coordinates, with semimajor and semiminor axes of 6 and 4.5 pixels, respectively. Background spectra were extracted from nearby source-free circular regions with 20-pixel diameter. In contrast, observations C1, C4, C13, and C14 captured the source closer to the optical axis. For these, a circular region of 5 pixels in diameter was used to extract source counts, encircling more than 90 per cent of the PSF, while background events were obtained from an annulus with inner and outer diameter of 8 and 16 pixels, respectively (represented in Fig. 1, left panel). For timing analysis, the `ciao` tool `axbary` was used for barycentric correction. The `dmextract` and `specextract` tools were used to extract the 1 source light curves and spectra, respectively. The extracted spectra were grouped to a minimum of 20 counts per bin.

2.3 Swift-XRT

The *Swift*-XRT observations were performed in photon counting (PC) mode. We analysed all available *Swift*-XRT (D. N. Burrows et al. 2005) data using the standard online processing tools provided by the UK Swift Science Data Centre (P. A. Evans et al. 2007, 2009). Source positions were determined using the simple

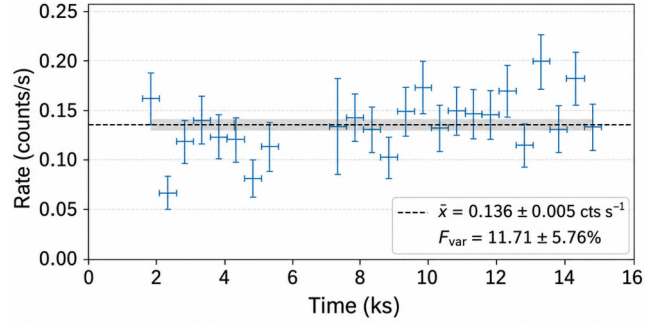


Figure 2. Background subtracted light curve with 500s bin-time from the *XMM-Newton* EPIC-pn module during the XM1 observation. The dashed line marks the mean count rate, while the shaded region indicates its uncertainty.

centroid method with the `simbad` coordinates of ULX-8 as input, adopting a 1 arcsec positional uncertainty. We selected only those observations with a detection significance more than 3σ , ensuring reliable source detection while minimizing contamination from background noise. We also investigated possible contamination from the nearby supernova SN2008ax. Using `ximage` we examined the region around the SN’s `simbad` position (RA = 187.6700°, Dec = 41.6378°) but did not detect any significant X-ray emission at the SN location in the *Swift*-XRT images. The angular separation between the ULX and the SN position is ~ 28 arcsec, above the *Swift*-XRT half-power diameter of ~ 18 arcsec, confirming that the ULX extraction is unaffected by the SN.

3 ANALYSIS

3.1 Timing analysis

To probe the time series, we generated light curves of all observations. Data from the pn module of *XMM-Newton* has been used for this analysis. We quantify the short-term variability within individual observations using the fractional root-mean-square (rms) variability amplitude, F_{var} , as defined by S. Vaughan et al. (2003). No statistically significant short-term variability is detected in the majority of the light curves. However, mild variability was observed in some observations, for example XM1 and XM4, with F_{var} of 11.71 ± 5.76 per cent and 11.74 ± 7.16 per cent respectively, for 500 s binned light curves. A representative light curve for XM1 is plotted in Fig. 2.

To search for possible periodicities in the source light curves, we used the `ftools` task `powspec` ⁶ v1.0 to generate the power spectra. No significant periodic signal was detected in any observation. To confirm this, we employed `hendrics` ⁷ v8.0.2 (M. Bachetti 2018), a set of `stingray`-based command-line scripts. Analysis with the `henacsearch` and `henzsearch` tasks of `hendrics` also revealed no pulsations in the light curves.

3.2 Hardness–intensity diagrams

Hardness–intensity diagrams (HIDs) have long been employed to track spectral state transitions in both ULXs and X-ray binaries (XRBs). In Galactic XRBs, HIDs plotting X-ray hardness versus

³<https://cxc.cfa.harvard.edu/ciao/>

⁴<https://cxc.cfa.harvard.edu/caldb/>

⁵<https://cxc.cfa.harvard.edu/ciao/threads/acisfptemp/>

⁶<https://heasarc.gsfc.nasa.gov/lheasoft/help/powspec.html>

⁷<https://hendrics.stingray.science/en/latest/>

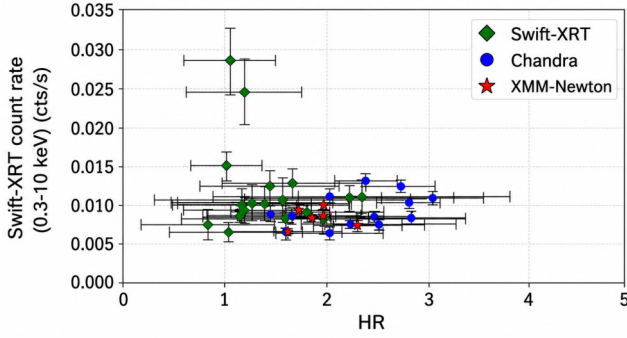


Figure 3. The hardness–intensity diagram: total 0.3–10 keV count rate versus HR, using observations from multiple instruments. Data points from *Swift*–XRT are shown in green, *Chandra* data in blue and *XMM*–*Newton* data in red.

intensity reveal characteristic *q-shaped* tracks that correspond to transitions among canonical states such as low/hard, high/soft and intermediate, as shown by GX 339–4’s 2002/2003 outburst (T. M. Belloni 2010). In ULXs, evolving patterns on the HID plane have been increasingly recognized: for instance, A. Gúrpide et al. (2021b) demonstrated recurrent spectral cycles between hard-ultraluminous and soft-ultraluminous regimes in sources like Holmberg II X-1 and NGC 5204 X-1 via HID tracking.

In Fig. 3, we present the HID of NGC 4490 ULX-8, where the hardness ratio (HR) is plotted as a function of the total 0.3–10 keV count rate converted to the *Swift*–XRT reference band. HR is computed as the ratio of the count rates in the 1.5–10 keV band to that in the 0.3–1.5 keV band. We find the HR of NGC 4490 ULX-8 to be in the range of 0.84–3.04 with typical measurement uncertainties ranging from ~ 0.15 to 1.45. To account for instrument differences, we have used the standard online *WebPIMMS*⁸ (K. Mukai 1993) tool to convert from *Chandra* and *XMM*–*Newton* count rates to XRT assuming a redshift of $z = 0.0018$ (M. A. Strauss et al. 1992).

We find that the most recent observations in our data set, S18 and S19, taken on 2022 December 1 and 2024 May 4 respectively exhibit significantly higher count rates compared to earlier epochs. However, no distinct hard or soft spectral states could be identified from the HID. The observed increase in count rate may therefore reflect changes in the accretion rate rather than a canonical state transition (S. Mondal et al. 2021).

3.3 Spectral analysis

We have used the X-ray spectral fitting package *xspec*⁹ version 12.13.0c (K. A. Arnaud 1996) for spectral analysis. All spectra are fit in the energy range of 0.3–10 keV. For *XMM*–*Newton*, MOS1, MOS2, and pn spectra are fit simultaneously. In a joint spectral fitting, the multiplicative normalization constant for the pn detector was fixed to unity, while the constants for the MOS detectors were allowed to vary to account for cross-calibration differences. In observation XM2, ULX-8 lies on the pn chip gap, leading to a flux drop; hence, for fitting purposes, the MOS1 detector’s constant value is set to unity for flux estimation.

We model the spectra using absorbed single-component models, namely an absorbed power-law (*tbabs*tbabs*powerlaw*;

PL) and an absorbed multicolour disc blackbody (*tbabs*tbabs*diskbb*; DISKBB; K. Mitsuda et al. 1984). Spectral fitting is performed in *xspec*, with absorption described by two *tbabs* components adopting abundances from J. Wilms, A. Allen & R. McCray (2000) and photoionization cross sections from D. A. Verner et al. (1996). The first absorption component is fixed to the Galactic hydrogen column density along the line of sight to NGC 4490, $N_{\text{H,Gal}} = 1.81 \times 10^{20} \text{ cm}^{-2}$ (P. M. W. Kalberla et al. 2005; V. Doroshenko 2024). The second component represents intrinsic absorption, $N_{\text{H,int}}$, associated with material within the host galaxy and/or the immediate environment of the source. Unless stated otherwise, $N_{\text{H,int}}$ is treated as a free parameter in the fits. The resulting best-fitting parameters for the *XMM*–*Newton* and *Chandra* observations are summarized in Table 2.

For the *Swift*–XRT observations, only the PL model parameters could be constrained for our data set (Table 3); consequently, DISKBB fits are not reported for these observations. In some fits (C5, C6, C10, C11, with DISKBB and S15, S17 with PL), the best-fitting value of $N_{\text{H,int}}$ is consistent with zero. In these cases, we report the upper uncertainty on $N_{\text{H,int}}$ to reflect the allowed range of intrinsic absorption.

A subset of the *Swift*–XRT observations (S7, S8, S9, and S14) lies at the lower end of the available counts and degrees of freedom, limiting the ability of the spectra to independently constrain absorption. Allowing $N_{\text{H,int}}$ to vary yields formally bounded values; however, in all four cases, the propagated uncertainties on the unabsorbed luminosity exceed 100 per cent of the best-fitting value. This behaviour indicating that luminosity estimates become dominated by absorption uncertainties in low-count spectra, rendering the resulting luminosity estimates physically uninformative.

Since the primary goal of our analysis is to track luminosity evolution, we therefore adopt a uniform approach and fix $N_{\text{H,int}}$ for these four observations to the mean value derived from the remaining *Swift*–XRT spectra, where absorption is better constrained. This procedure ensures stable estimates of the unabsorbed luminosity while retaining sensitivity to genuine spectral variability through the remaining free parameters.

We find that both the PL and DISKBB models provide statistically acceptable fits to the *XMM*–*Newton* and *Chandra* spectra. For previously analysed epochs of NGC 4490 ULX-8, the derived parameters are consistent with earlier studies and the adequacy of both models is in agreement with results reported for NGC 4490 ULX-8 as well as for other ULXs such as NGC 253 X-9 and NGC 1313 ULX-2 (J. J. E. Kajava & J. Poutanen 2009). All best-fitting spectra are presented in Appendix A.

In addition to the PL and DISKBB models, we explored alternative spectral models like *tbabs*tbabs*diskpbb* (DISKPBB) and *tbabs*tbabs*cutoffpl* (CUTOFFPL). The DISKPBB model represents a generalized multicolour disc where the local disc temperature scales with radius as $T(r) \propto r^{-p}$, with p as a free parameter (S. Mineshige et al. 1994; A. Kubota et al. 2005). The standard thin disc (DISKBB) is recovered for $p = 0.75$, while $p = 0.5$ corresponds to the slim-disc regime (M. A. Abramowicz et al. 1988). Our fits using DISKPBB yielded unconstrained p values across all the observations except for XM5 (the epoch with the highest post-reduction exposure), where we obtained $p = 0.71^{+0.22}_{-0.10}$. Fixing $p = 0.5$ to mimic a slim-disc scenario produced fits that were worse or unchanged in 18 out of 20 (all except XM6 and C8) *Chandra* and *XMM*–*Newton* observations compared to $p = 0.75$, favouring a standard thin-disc interpretation.

⁸<https://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3pimms/w3pimms.pl>

⁹<https://heasarc.gsfc.nasa.gov/xanadu/xspec/>

Table 2. Best-fitting spectral parameters for NGC 4490 ULX-8 across different *Chandra* and *XMM-Newton* observations, obtained using the `tbabs*tbabs*powerlaw` and `tbabs*tbabs*diskbb` models.

Epoch	Model	$N_{\text{H,int}}^{\text{a}}$ (10^{22} cm^{-2})	Γ^{b}	T_{in}^{c} (keV)	Disc Norm (N^{d}) (10^{-2})	Unabsorbed L_X^{e} ($10^{39} \text{ erg s}^{-1}$)	Absorbed L_X^{e} ($10^{39} \text{ erg s}^{-1}$)	$\chi^2/\text{d.o.f.}^{\text{f}}$	Simfist $p\text{-value}^{\text{g}}$
C1	PL	$1.18^{+0.20}_{-0.18}$	$2.16^{+0.21}_{-0.20}$	—	—	$6.73^{+1.01}_{-0.76}$	$3.53^{+0.29}_{-0.28}$	47.58/41	0.03
	DISKBB	$0.73^{+0.13}_{-0.12}$	—	$1.22^{+0.14}_{-0.12}$	$1.40^{+0.76}_{-0.50}$	$4.39^{+0.33}_{-0.32}$	$3.21^{+0.26}_{-0.25}$	39.58/41	0.77
C2	PL	$1.26^{+0.17}_{-0.15}$	$2.67^{+0.19}_{-0.18}$	—	—	$5.76^{+1.02}_{-0.77}$	$2.11^{+0.14}_{-0.13}$	73.63/55	$4 \times 10^{-3\text{h}}$
	DISKBB	0.67 ± 0.10	—	$0.97^{+0.08}_{-0.07}$	$2.43^{+0.97}_{-0.69}$	$2.90^{+0.20}_{-0.19}$	1.98 ± 0.12	58.67/55	0.56
C3	PL	$1.00^{+0.15}_{-0.13}$	$2.06^{+0.15}_{-0.14}$	—	—	$5.78^{+0.56}_{-0.47}$	$3.34^{+0.19}_{-0.18}$	85.92/73	0.05
	DISKBB	$0.52^{+0.10}_{-0.09}$	—	$1.37^{+0.13}_{-0.11}$	$0.79^{+0.32}_{-0.23}$	3.93 ± 0.21	3.13 ± 0.18	84.72/73	0.05
C4	PL	$1.13^{+0.69}_{-0.60}$	$2.36^{+0.51}_{-0.47}$	—	—	$4.85^{+2.84}_{-1.33}$	$2.28^{+0.34}_{-0.31}$	20.46/15	0.12
	DISKBB	$0.42^{+0.47}_{-0.41}$	—	$1.14^{+0.31}_{-0.21}$	$1.14^{+1.74}_{-0.72}$	$2.66^{+0.47}_{-0.38}$	$2.09^{+0.34}_{-0.27}$	17.95/15	0.54
C5	PL	$0.61^{+0.51}_{-0.45}$	$1.92^{+0.37}_{-0.34}$	—	—	$2.90^{+0.83}_{-0.50}$	$1.98^{+0.26}_{-0.22}$	12.06/21	0.51
	DISKBB	<0.29	—	$1.59^{+0.26}_{-0.20}$	$0.23^{+0.14}_{-0.09}$	1.99 ± 0.18	1.97 ± 0.18	13.36/21	0.24
C6	PL	$0.33^{+0.46}_{-0.33}$	$1.74^{+0.37}_{-0.33}$	—	—	$2.52^{+0.55}_{-0.35}$	$2.02^{+0.35}_{-0.25}$	18.80/21	0.45
	DISKBB	<0.15	—	$1.62^{+0.31}_{-0.23}$	$0.20^{+0.16}_{-0.09}$	1.92 ± 0.18	1.90 ± 0.18	24.27/21	0.05
C7	PL	$1.24^{+0.45}_{-0.40}$	$2.49^{+0.33}_{-0.30}$	—	—	$5.29^{+1.95}_{-1.17}$	$2.21^{+0.20}_{-0.19}$	15.51/28	0.75
	DISKBB	$0.34^{+0.29}_{-0.26}$	—	$1.19^{+0.19}_{-0.16}$	$0.91^{+0.79}_{-0.43}$	$2.60^{+0.28}_{-0.25}$	$2.14^{+0.21}_{-0.19}$	18.98/28	0.17
C8	PL	$0.87^{+0.29}_{-0.27}$	$2.28^{+0.24}_{-0.23}$	—	—	$6.12^{+1.30}_{-0.91}$	$3.26^{+0.25}_{-0.24}$	39.50/40	0.81
	DISKBB	$0.15^{+0.20}_{-0.15}$	—	$1.30^{+0.19}_{-0.15}$	$0.88^{+0.61}_{-0.37}$	$3.51^{+0.27}_{-0.26}$	$3.17^{+0.29}_{-0.26}$	51.73/40	$4 \times 10^{-3\text{h}}$
C9	PL	$1.19^{+0.29}_{-0.26}$	$2.49^{+0.22}_{-0.21}$	—	—	$9.00^{+2.04}_{-1.43}$	3.83 ± 0.24	42.27/50	0.10
	DISKBB	$0.42^{+0.18}_{-0.16}$	—	$1.15^{+0.11}_{-0.10}$	$1.92^{+0.98}_{-0.65}$	$4.64^{+0.35}_{-0.32}$	$3.66^{+0.24}_{-0.23}$	37.88/50	0.62
C10	PL	$0.49^{+0.37}_{-0.33}$	$2.11^{+0.28}_{-0.26}$	—	—	$3.70^{+0.88}_{-0.59}$	$2.47^{+0.28}_{-0.23}$	28.15/30	0.22
	DISKBB	<0.13	—	$1.31^{+0.14}_{-0.12}$	$0.58^{+0.26}_{-0.19}$	2.45 ± 0.17	2.42 ± 0.17	28.60/30	0.19
C11	PL	$0.68^{+0.44}_{-0.39}$	$2.25^{+0.33}_{-0.30}$	—	—	$4.15^{+1.28}_{-0.79}$	$2.41^{+0.28}_{-0.23}$	20.44/28	0.36
	DISKBB	<0.82	—	$1.26^{+0.14}_{-0.12}$	$0.68^{+0.31}_{-0.22}$	$2.45^{+0.18}_{-0.17}$	$2.41^{+0.19}_{-0.16}$	19.67/28	0.51
C12	PL	$1.36^{+0.34}_{-0.3}$	$2.53^{+0.22}_{-0.21}$	—	—	$9.39^{+2.36}_{-1.65}$	$3.70^{+0.23}_{-0.22}$	49.53/50	$4 \times 10^{-3\text{h}}$
	DISKBB	$0.43^{+0.22}_{-0.19}$	—	$1.21^{+0.12}_{-0.11}$	$1.55^{+0.79}_{-0.53}$	$4.60^{+0.37}_{-0.34}$	3.65 ± 0.23	35.98/50	0.91

Table 2 – continued

Epoch	Model	$N_{\text{H,int}}^a$ (10^{22} cm^{-2})	Γ^b	T_{in}^c (keV)	Disc Norm (N) ^d (10^{-2})	Unabsorbed L_X^e ($10^{39} \text{ erg s}^{-1}$)	Absorbed L_X^e ($10^{39} \text{ erg s}^{-1}$)	$\chi^2/\text{d.o.f.}^f$	Simfist p -value ^g
C13	PL	$1.27^{+0.58}_{-0.50}$	$2.38^{+0.36}_{-0.33}$	–	–	$5.78^{+2.45}_{-1.37}$	$2.59^{+0.24}_{-0.23}$	25.48/37	0.02
	DISKBB	$0.41^{+0.38}_{-0.33}$	–	$1.23^{+0.21}_{-0.17}$	$0.96^{+0.89}_{-0.47}$	$3.09^{+0.38}_{-0.35}$	$2.48^{+0.26}_{-0.23}$	18.84/37	0.27
C14	PL	$1.35^{+0.47}_{-0.41}$	$2.65^{+0.3}_{-0.27}$	–	–	$6.75^{+2.61}_{-1.59}$	$2.44^{+0.19}_{-0.18}$	41.13/34	$6 \times 10^{-3 \text{ h}}$
	DISKBB	$0.34^{+0.29}_{-0.26}$	–	$1.14^{+0.15}_{-0.13}$	$1.26^{+0.91}_{-0.52}$	$3.01^{+0.34}_{-0.30}$	$2.45^{+0.22}_{-0.20}$	30.45/34	0.35
XM1	PL	$0.93^{+0.15}_{-0.13}$	$2.56^{+0.19}_{-0.17}$	–	–	$5.66^{+0.97}_{-0.76}$	2.50 ± 0.21	69.07/66	0.02
	DISKBB	$0.41^{+0.09}_{-0.08}$	–	$0.99^{+0.09}_{-0.08}$	$2.28^{+1.01}_{-0.69}$	$3.04^{+0.27}_{-0.26}$	2.31 ± 0.19	61.44/66	0.26
XM2	PL	$0.71^{+0.17}_{-0.14}$	$2.22^{+0.18}_{-0.17}$	–	–	$3.83^{+0.63}_{-0.51}$	$2.22^{+0.21}_{-0.20}$	96.81/62	0.00^{h}
	DISKBB	$0.28^{+0.10}_{-0.08}$	–	$1.21^{+0.11}_{-0.10}$	$0.86^{+0.38}_{-0.26}$	$2.60^{+0.26}_{-0.25}$	2.20 ± 0.20	68.21/62	0.34
XM3	PL	$0.77^{+0.10}_{-0.09}$	2.18 ± 0.13	–	–	$5.05^{+0.46}_{-0.40}$	$2.94^{+0.19}_{-0.20}$	225.36/213	0.00^{h}
	DISKBB	0.39 ± 0.06	–	$1.16^{+0.09}_{-0.08}$	$1.33^{+0.44}_{-0.33}$	3.38 ± 0.21	$2.71^{+0.19}_{-0.18}$	191.03/213	0.50
XM4	PL	$0.91^{+0.18}_{-0.16}$	$2.37^{+0.21}_{-0.19}$	–	–	$4.91^{+0.89}_{-0.68}$	$2.45^{+0.23}_{-0.22}$	60.29/49	0.02
	DISKBB	$0.43^{+0.10}_{-0.09}$	–	$1.12^{+0.11}_{-0.10}$	$1.32^{+0.66}_{-0.43}$	$2.94^{+0.28}_{-0.27}$	$2.30^{+0.21}_{-0.20}$	51.95/49	0.68
XM5	PL	0.87 ± 0.07	$2.55^{+0.09}_{-0.08}$	–	–	$3.83^{+0.32}_{-0.28}$	1.75 ± 0.07	251.87/166	0.00^{h}
	DISKBB	0.37 ± 0.04	–	1.06 ± 0.04	$1.27^{+0.24}_{-0.20}$	$2.19^{+0.10}_{-0.09}$	1.73 ± 0.07	154.28/166	0.84
XM6	PL	$0.74^{+0.08}_{-0.07}$	2.20 ± 0.10	–	–	$4.17^{+0.31}_{-0.28}$	2.41 ± 0.12	112.49/123	3×10^{-3}
	DISKBB	0.35 ± 0.04	–	1.24 ± 0.07	$0.84^{+0.22}_{-0.17}$	2.82 ± 0.14	2.32 ± 0.12	119.34/123	$1 \times 10^{-3 \text{ h}}$

Note. Parameter uncertainties are quoted at the 90 per cent confidence level.

^aIntrinsic hydrogen column density.

^bPhoton index.

^cInner disc temperature of the DISKBB component.

^dDISKBB normalization values.

^eLuminosity calculated in the 0.5–8 keV band.

^f χ^2 and degrees of freedom; the lower reduced χ^2 per observation is highlighted.

^gF-test statistic and corresponding probability with respect to $\text{tbabs} * \text{tbabs}(\text{powerlaw} + \text{diskbb})$.

^hProbability value < 0.01 .

Table 3. Best-fitting spectral parameters for NGC 4490 ULX-8 from different *Swift*-XRT observations, obtained using the `tbabs*tbabs*powerlaw` model.

Epoch	Count rate ^a (10^{-2} cts s $^{-1}$)	Exposure time (ks)	$N_{\text{H,int}}$ ^b (10^{22} cm $^{-2}$)	Γ ^c	Unabsorbed L_X ^d (10^{39} erg s $^{-1}$)	Absorbed L_X ^d (10^{39} erg s $^{-1}$)	C-stat/d.o.f. ^e
S1	1.475 ± 0.176	4.93	$0.32^{+0.18}_{-0.14}$	$2.08^{+0.38}_{-0.34}$	$6.16^{+1.31}_{-0.96}$	$4.53^{+0.81}_{-0.69}$	63.43/60
S2	1.270 ± 0.178	4.23	$0.49^{+0.30}_{-0.23}$	$1.84^{+0.44}_{-0.40}$	$6.67^{+1.70}_{-1.14}$	$4.89^{+1.04}_{-0.86}$	48.71/48
S3	1.220 ± 0.203	3.13	$0.25^{+0.24}_{-0.18}$	$1.45^{+0.43}_{-0.40}$	$5.88^{+1.25}_{-1.05}$	$5.14^{+1.28}_{-1.04}$	38.24/35
S4	1.069 ± 0.162	4.28	$0.51^{+0.60}_{-0.40}$	$1.35^{+1.07}_{-0.91}$	$7.94^{+4.93}_{-1.99}$	$6.59^{+5.81}_{-2.75}$	31.82/35
S5	0.736 ± 0.196	2.04	$0.25^{+0.40}_{-0.25}$	$1.83^{+1.12}_{-0.95}$	$3.74^{+1.92}_{-1.12}$	$3.06^{+2.43}_{-1.18}$	10.25/13
S6	1.013 ± 0.226	2.21	$0.75^{+0.59}_{-0.41}$	$2.34^{+0.81}_{-0.69}$	$6.82^{+6.02}_{-2.14}$	$3.67^{+1.26}_{-0.93}$	27.69/21
S7	0.837 ± 0.219	1.88	0.47 (fixed)	1.50 ± 0.48	$4.65^{+1.58}_{-1.20}$	$3.77^{+1.61}_{-1.15}$	15.79/14
S8	0.989 ± 0.200	2.60	0.47 (fixed)	2.10 ± 0.43	$5.78^{+1.32}_{-1.07}$	$3.87^{+1.38}_{-0.98}$	20.48/22
S9	1.009 ± 0.212	2.36	0.47 (fixed)	2.00 ± 0.41	$5.45^{+1.29}_{-1.08}$	$3.81^{+1.29}_{-0.99}$	14.88/22
S10	0.896 ± 0.127	5.85	$0.44^{+0.40}_{-0.30}$	$1.46^{+0.51}_{-0.47}$	$5.12^{+1.07}_{-0.87}$	$4.22^{+1.10}_{-0.86}$	31.48/50
S11	0.839 ± 0.146	4.17	$0.11^{+0.26}_{-0.11}$	$0.92^{+0.50}_{-0.46}$	$5.39^{+1.65}_{-1.21}$	$5.19^{+1.78}_{-1.32}$	29.14/32
S12	0.646 ± 0.126	4.35	$0.28^{+0.32}_{-0.22}$	$1.99^{+0.70}_{-0.61}$	$3.07^{+1.16}_{-0.70}$	$2.38^{+0.87}_{-0.61}$	23.93/22
S13	0.852 ± 0.082	13.20	$0.32^{+0.14}_{-0.12}$	$1.74^{+0.27}_{-0.26}$	$4.24^{+0.54}_{-0.48}$	$3.42^{+0.50}_{-0.43}$	95.74/94
S14	1.091 ± 0.217	2.48	0.47 (fixed)	1.42 ± 0.34	$6.17^{+1.44}_{-1.20}$	$5.09^{+1.43}_{-1.15}$	29.18/24
S15	0.818 ± 0.193	2.44	< 0.25	$0.97^{+0.60}_{-0.39}$	$5.13^{+2.30}_{-1.57}$	$5.10^{+2.30}_{-1.57}$	21.08/18
S16	0.917 ± 0.161	3.84	$0.81^{+0.48}_{-0.40}$	$2.65^{+0.73}_{-0.65}$	$6.85^{+5.99}_{-2.35}$	$3.00^{+0.83}_{-0.64}$	46.46/31
S17	1.048 ± 0.278	1.49	< 0.20	$0.99^{+0.58}_{-0.43}$	$5.81^{+3.27}_{-2.04}$	$5.77^{+3.27}_{-2.04}$	15.59/14
S18	2.435 ± 0.405	1.52	$0.68^{+0.49}_{-0.37}$	$2.28^{+0.75}_{-0.66}$	$14.90^{+10.23}_{-3.92}$	$8.51^{+2.73}_{-1.95}$	23.75/33
S19	2.818 ± 0.417	1.66	$0.85^{+0.42}_{-0.32}$	$2.68^{+0.62}_{-0.55}$	$20.75^{+14.82}_{-6.22}$	$8.74^{+2.00}_{-1.59}$	39.2/40

Note. Parameter uncertainties are quoted at the 1σ confidence level.

^aTotal count rate in the 0.3–10 keV band.

^bIntrinsic hydrogen column density.

^cPhoton index.

^dLuminosity in the 0.5–8 keV band.

^eC-statistic and degrees of freedom.

Similarly, the CUTOFFPL model, which introduces an exponential high-energy cutoff to the power-law, returned unconstrained cutoff energies across all 20 observations. However, spectral turnovers at ~ 5 –8 keV have been reported (e.g. T. P. Roberts et al. 2010, A. M. Stobbart, T. P. Roberts & J. Wilms 2006). We test it by freezing the cutoff at 7.1 keV (D. J. Walton et al. 2020), which allowed the model to fit the spectra adequately, suggesting a possible high-energy cutoff but it remains unmeasurable for NGC 4490 ULX-8 given the current statistical quality of the data.

With these results, we adopt the simpler DISKBB and PL models, which provide stable and well-constrained fits across all observations and are consistent with previous studies of the same ULX.

The convolution model `cflux` in `xspec` is used to estimate fluxes (F_X) in the 0.5–8 keV band (to maintain consistency with previous studies). For power-law models, X-ray luminosities are computed assuming isotropic emission as $L_X = 4\pi d^2 F_X$, where d is the source distance. For disc models (e.g. `diskbb`), the luminosity is computed as $L_X = 2\pi d^2 F_X / \cos \theta$. In the absence of inclination constraints, we adopt $\theta = 60^\circ$.

Uncertainties are quoted at the 90 per cent confidence level for one interesting parameter for the *XMM-Newton* and *Chandra* observations (Table 2) and at the 1σ level for the XRT observations (Table 3).

3.3.1 *F*-test

We tested two-component models such as PL + DISKBB, but they generally did not yield constrained parameters or a statistically significant improvement. To quantify this, we used `xspec`'s `simttest`¹⁰ (R. Protassov et al. 2002) with 1000 simulations for each comparison (PL versus PL + DISKBB and DISKBB versus PL + DISKBB). The resulting *p*-values, reported in Table 2, show that the majority of cases have $p > 0.01$, while some with $p < 0.01$ involve unphysical or unconstrained parameters (see K. C. Dage et al. 2019), limiting the physical interpretability of those fits. We therefore adopt single-component models (PL or DISKBB) as sufficient to describe the available data for this source.

4 RESULTS

4.1 Long-term spectral variability

We examine the long-term spectral variability of NGC 4490 ULX-8 across the full observational baseline (Fig. 4)

¹⁰<https://heasarc.gsfc.nasa.gov/docs/software/xspec/manual/node126.html>

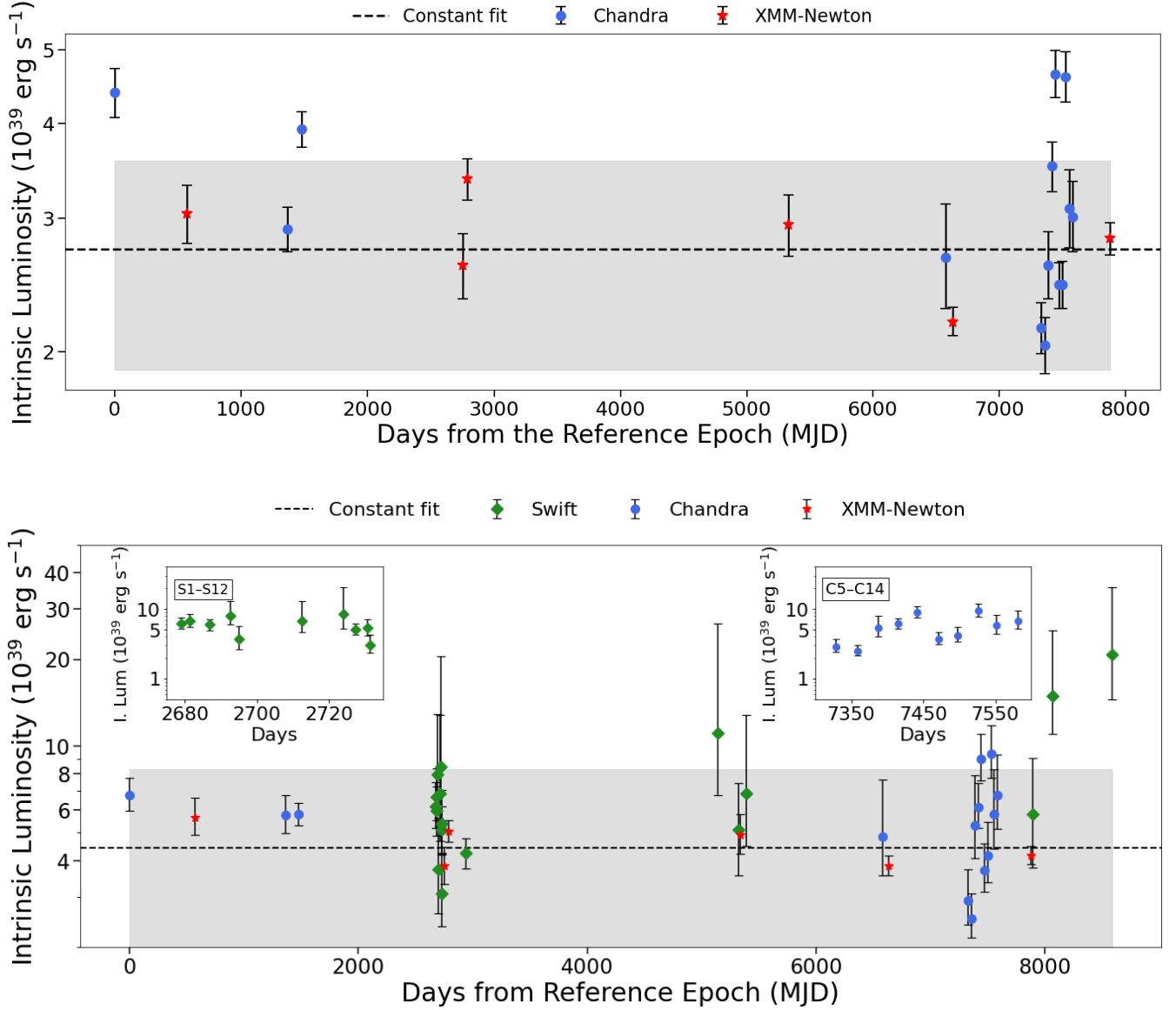


Figure 4. Unabsorbed luminosity versus time graphs for NGC 4490 ULX-8 with the best-fitting horizontal line and its RMS error denoted by the shaded region. The oldest observation (C1 with MJD = 51851) is taken as the reference epoch. The Y-axis is logarithmically scaled for better visualization. *Upper:* XMM-Newton and Chandra DISKBB luminosity values. *Lower:* XMM-Newton, Chandra and Swift-XRT PL luminosity values along with the two zoom in plots for the S1-S12 and C5-C14 observation samples.

using unabsorbed luminosities derived from both spectral DISKBB and PL fits. We fit a constant luminosity model to the data using `scipy.optimize.curve_fit`¹¹, shown as a dashed horizontal line in the figure. The root mean square (RMS) error, representing the deviation of the data points from the best-fitting line, is indicated by the shaded region. To assess the overall goodness of fit, we compute the reduced chi-squared (χ^2) statistic. With DISKBB, the mean unabsorbed luminosity is $L_X = 2.73 \times 10^{39} \text{ erg s}^{-1}$ with an RMS scatter of $0.84 \times 10^{39} \text{ erg s}^{-1}$, yielding a poor fit under the assumption

of constant luminosity ($\chi^2_v = 10.36$). For the absorbed power-law model, the mean is $L_X = 4.46 \times 10^{39} \text{ erg s}^{-1}$ with an RMS of $3.55 \times 10^{39} \text{ erg s}^{-1}$, still inconsistent with strict constancy ($\chi^2_v = 1.68$) but markedly better than DISKBB.

We next examine luminosity changes on intermediate (weeks-months) time-scales by focusing on two regularly sampled subsets: the Chandra C5-C14 observations and the Swift-XRT S1-S12 monitoring. (Fig. 4, lower panels). The inferred variability factors are 3.73 ± 1.04 for the Chandra sample and 2.59 ± 1.37 for the Swift-XRT sample.

These measurements demonstrate statistically significant variability on both multiyear and week-month time-scales, with the inferred amplitude depending on the adopted spectral model.

¹¹https://docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.curve_fit.html

Table 4. Results of Pearson’s linear correlation test and Spearman’s rank correlation test applied for Γ versus N_H , L_X versus Γ (free N_H). Reported are the correlation coefficients (r) and the associated two-sided p -values.

		Γ versus N_H	L_X versus Γ (free N_H)
Pearson linear test	r -value	0.76	0.58
	p -value	9.11×10^{-5}	6.93×10^{-3}
Spearman rank test	r -value	0.71	0.50
	p -value	4.68×10^{-4}	2.41×10^{-2}

Table 5. LINMIX regression results for Γ versus N_H , L_X versus Γ (free N_H) and L_X versus Γ (fixed N_H). Reported statistic are the best-fitting slope β and the 1σ confidence interval (CI) on β , posterior probability that the slope is positive [$P(\beta > 0)$] and the equivalent Gaussian significance (z_{eq}).

Statistic	Γ versus N_H	L_X versus Γ (free N_H)	L_X versus Γ (fixed N_H)
β	1.13	0.46	0.41
1σ CI on β	[0.13, 1.49]	[0.01, 0.79]	[−0.03, 0.84]
$P(\beta > 0)$	0.87	0.85	0.82
z_{eq}	1.15 σ	1.01 σ	0.91 σ

4.2 Powerlaw parameter correlation analysis

We examine correlations between spectral parameters derived from absorbed power-law (PL) fits by considering three cases: (i) the relation between the photon index Γ and intrinsic absorption N_H ; (ii) the relation between unabsorbed X-ray luminosity L_X and Γ with N_H free across epochs; and (iii) the relation between L_X and Γ with N_H tied across epochs. Throughout this section, the X-ray luminosity is expressed as $\log L_X \equiv \log_{10}(L_X/10^{39} \text{ erg s}^{-1})$.

Correlations are first quantified using Pearson’s linear correlation and Spearman’s rank correlation tests, which measure linear and monotonic trends, respectively, without accounting for measurement uncertainties. The resulting correlation coefficients and associated two-sided p -values are listed in Table 4. A strong positive correlation is found between Γ and N_H , with both tests yielding statistically significant results. For the L_X – Γ relation with N_H free, the Pearson and Spearman tests indicate a moderate but statistically significant positive correlation. In the case where N_H is tied across epochs, Pearson and Spearman tests yield statistically insignificant results, motivating the use of advanced regression methods.

To incorporate measurement uncertainties in both variables, we apply the hierarchical Bayesian regression method `linmix` (B. C. Kelly 2007). Since `linmix` does not accommodate asymmetric uncertainties, we approximate asymmetric uncertainties by the mean of the upper and lower error estimates for each parameter. The resulting regression slopes and associated statistical measures are summarized in Table 5 and shown in Fig. 5.

For all three relations examined, the inferred slopes β are positive but not tightly constrained at the 1σ level (Table 5). We therefore characterize the strength of each trend using the posterior probability that the slope is positive, $P(\beta > 0)$ and the corresponding equivalent one-sided Gaussian significance, z_{eq} . Values of $P(\beta > 0) \simeq 0.5$ (or $z_{eq} \simeq 0$) indicate no preference for a positive or negative trend, while progressively larger values reflect increasing evidence for a positive correlation.

In the tied- N_H analysis, three observations (XM5, C1 and C3; shown in grey in Fig. 5) lie well outside the main locus defined by the majority of the data and exert strong leverage on the in-

ferred regression slope. Notably, these same observations align well with the Γ – N_H correlation and also follow the L_X – Γ relation in the case where N_H is allowed to vary freely, indicating that for these epochs the inferred relation is largely driven by absorption-related effects.

Excluding these three observations reveals that the remaining 17 out of 20 epochs define a coherent locus in the L_X – Γ plane, with a weak but systematic positive trend. The corresponding `linmix` regression yields a positive slope with $P(\beta > 0) = 0.82$, although the slope remains only marginally constrained. This demonstrates that the observed L_X – Γ trend is characteristic of the majority of the data set but is not representative of all epochs.

Overall, the results indicate a strong Γ – N_H correlation and a weak, population-dominated L_X – Γ trend. For most observations, the L_X – Γ relation is consistent with reflecting intrinsic spectral behaviour once absorption-related effects are controlled. The physical implications of these correlations are discussed in Section 5.2.

4.3 Disc properties and compact-object constraints

Using parameters from the DISKBB fits, we examine the relation between inner disc temperature (T_{in}) and unabsorbed luminosity (L_X), and obtain model-dependent estimates of the characteristic disc radius and compact-object mass.

A `linmix` regression applied to the logarithmic L_X – T_{in} measurements yields a posterior median slope of $\beta = 2.44$, with $P(\beta > 0) = 0.90$ and $z_{eq} \simeq 1.28\sigma$. The slope is positive but weakly constrained, with a 68 per cent confidence interval of [0.51, 4.48].

In performing the regression analysis, we restrict the sample to observations for which the spectral parameters are reliably constrained. A small subset of observations yields intrinsic absorption values whose best-fitting values are driven to the lower bound ($N_{H,int} = 0$, Section 3.3). In such cases, degeneracies between absorption, continuum shape and disc normalization lead to poorly constrained parameters and increased model dependence. To avoid biasing the regression by these effects, we exclude these observations from the L_X – T_{in} analysis (Fig. 6), where reliable disc parameters cannot be recovered.

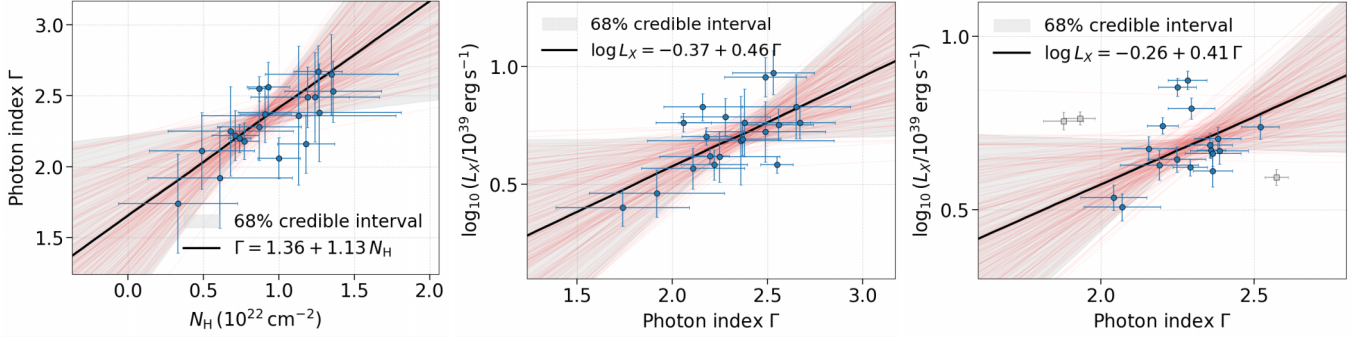


Figure 5. `linmix` regression results of spectral parameters obtained from PL fits to *XMM-Newton* and *Chandra* observations. *Left:* Γ versus N_H . *Middle:* L_X versus Γ with N_H allowed to vary freely across observations. *Right:* L_X versus Γ with N_H tied across observations; three discrepant observations (XM5, C1, C3; shown in grey) are excluded from the regression to assess the behaviour of the remaining epochs (see Section 4.2). In all panels, the black line shows the posterior median regression, while the grey shaded region indicates the 1σ credible interval derived from the `linmix` MCMC samples.

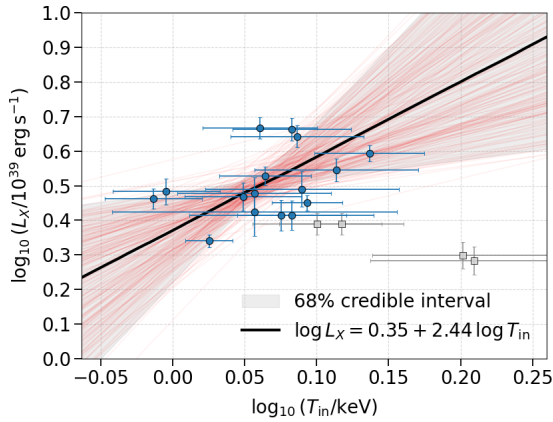


Figure 6. Log-log plot of disc luminosity versus inner disc temperature for ULX-8. The black line shows the posterior median regression, while the grey shaded region indicates the 1σ credible interval derived from the `linmix` MCMC samples. Grey data points correspond to observations excluded from the fit due to poorly constrained disc parameters.

Although the DISKBB model is a phenomenological description, its normalization parameter (N) can be mapped to a characteristic inner disc radius (R_{in}) and an associated compact-object mass (M_{BH} under standard geometric and spectral assumptions).

We use the highest quality *XMM-Newton* spectral fits, which have the highest signal-to-noise ratios and degrees of freedom, to derive an average DISKBB normalization. *XMM*'s larger effective area in the soft X-ray band provides the strongest constraints on the thermal disc component, minimizing cross-instrument systematics in the inferred disc parameters. The relation between R_{in} and N is given by:

$$R_{in} = \xi \kappa^2 N^{1/2} (\cos \theta)^{-1/2} d_{10 \text{ kpc}} \text{ km}, \quad (1)$$

where θ is the inclination angle of the disc, $d_{10 \text{ kpc}}$ is the source distance from us in 10 kpc units. ξ, κ are the two correction factors where ξ is the geometric factor and κ is the hardening factor for observed colour temperature. In the case of a standard accretion disc, $\xi \approx 0.412$ (A. Kubota et al. 1998) and $\kappa \approx 1.7$ (T. Shimura & F. Takahara 1995). Using the R_{in} values, M_{BH} can be determined

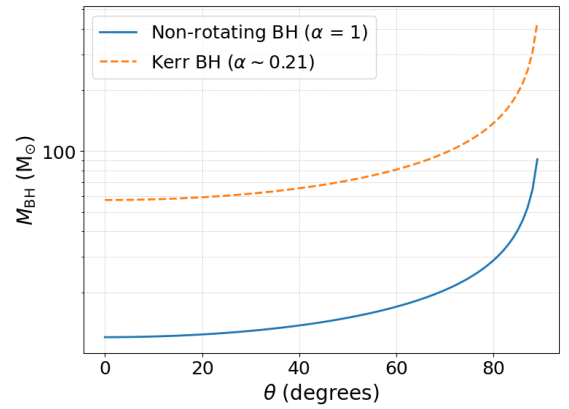


Figure 7. *Top:* variation of black hole mass (M_{BH}) with inclination angle (θ) for non-rotating (Schwarzschild, $a = 1$) and rotating (Kerr, $a = 0.21$) cases, derived from absorbed multicolour disc blackbody model normalization.

from this equation:

$$M_{BH} = R_{in} c^2 / (6G\alpha), \quad (2)$$

where c is the speed of light and G is the gravitational constant. α depends on the spin parameter (a^*) such that $\alpha \approx 0.21$ for a rapidly rotating (Kerr) BH and $\alpha = 1$ for a non-rotating BH. We find $R_{in} \sim 107 \times (\cos \theta)^{-1/2} \text{ km}$ and consequently $M_{BH} \sim 12 \times (\cos \theta)^{-1/2} / \alpha$. Fig. 7 shows the dependence of the inferred mass on inclination and spin across the full physically allowed range.

In the absence of independent constraints on the disc inclination, we adopt a representative value of $\theta = 60^\circ$, commonly used in ULX studies (e.g. D. J. Walton et al. 2020) and explained in R. Urquhart & R. Soria (2016). Under this assumption, we obtain $R_{in} \sim 151 \text{ km}$ and $M_{BH} \sim 81 M_\odot$ for a Kerr BH and $\sim 17 M_\odot$ for a non-rotating BH.

5 DISCUSSIONS

5.1 Variability, spectral states, and accretion regime

We interpret the observed long- and short-time-scale variability of NGC 4490 ULX-8 within the framework of ULX spectral states

and accretion regimes, noting that steady emission is disfavoured on multiyear time-scales under both spectral models. The inferred variability amplitude depends on the adopted spectral description, with the power-law model yielding higher luminosities and larger scatter than DISKBB. This difference may arise from the model-dependent high-energy extrapolation inherent to the power-law description, as well as from differences in the fitted spectral parameters across epochs.

A. D. Sutton, T. P. Roberts & M. J. Middleton (2013) classified ULXs into three spectral regimes: hard ultraluminous, soft ultraluminous and broadened disc, based on spectral morphology, curvature and variability properties. Across all epochs, the X-ray spectra of NGC 4490 ULX-8 are dominated by a smooth, single curved continuum in the 0.3–10 keV band, with a spectral peak at ~ 1 –2 keV and a monotonic decline toward higher energies. No persistent hard excess above ~ 5 –6 keV or distinct soft excess at low energies is observed. Although both PL and DISKBB models provide statistically acceptable fits in individual epochs, two-component models are not required by formal model comparison and remain unconstrained by the available data, indicating intrinsically single-component spectral curvature rather than multiple physically distinct emission components.

These properties, together with disc-dominated fits yielding luminosities of a few $\times 10^{39}$ erg s $^{-1}$, place ULX-8 in the broadened-disc regime. The L_X – T_{in} relation provides a consistency check on the accretion flow; however, the inferred slopes are weakly constrained and remain compatible, within uncertainties, with both thin-disc ($L_X \propto T_{\text{in}}^4$; N. I. Shakura & R. A. Sunyaev 1973) and slim-disc ($L_X \propto T_{\text{in}}^2$; K.-y. Watarai, T. Mizuno & S. Mineshige 2001) scalings, and therefore do not uniquely distinguish between accretion regimes. Considered together with the persistent spectral morphology, luminosity range, and absence of state transitions, the results are consistent with the source remaining in a single accretion regime, with accretion near the Eddington limit.

The observed spectral variability is therefore most naturally attributed to changes in the curvature of the dominant continuum rather than transitions between distinct accretion states. Several mechanisms could contribute to such variability on multiyear time-scales, including modulation of the mass transfer rate from the donor star, potentially driven by stellar activity cycles (J. H. Applegate 1992; M. M. Kotze & P. A. Charles 2012), or changes in the accretion geometry at near- or super-Eddington rates, such as variations in wind strength, funnel opening angle, or line-of-sight obscuration (M. J. Middleton et al. 2015; A. Grpide et al. 2021a).

On shorter (week–month) time-scales, luminosity variations of up to a factor of ~ 4 remain consistent with persistent to moderately variable behaviour reported in other ULXs (H. P. Earnshaw et al. 2025), such as M51 ULX-8 and NGC 4490 ULX-4 and in high-mass X-ray binaries.

5.2 Spectral correlations and implications for the compact object

Correlations between spectral parameters derived from absorbed power-law fits have been widely reported in ULXs and used as diagnostics of spectral variability, though these are potentially affected by model degeneracies (e.g. J. J. E. Kajava & J. Poutanen 2009).

When intrinsic absorption is allowed to vary freely across epochs in NGC 4490 ULX-8, a positive L_X – Γ correlation is observed, accompanied by a strong Γ – N_{H} correlation. This covariance is expected in absorbed power-law models: increases in N_{H}

suppress soft photons and are naturally compensated by steeper photon indices. Because unabsorbed luminosity depends sensitively on both parameters, this coupling can artificially enhance the apparent L_X – Γ correlation when absorption is removed using the fitted values.

When intrinsic absorption is instead tied across epochs, the behaviour changes markedly. A small subset of observations deviates from the main L_X – Γ locus, but the remaining majority of epochs define a weak, statistically significant positive trend. This indicates that while absorption-related effects dominate a few epochs, most observations retain a consistent spectral response when absorption-driven variability is controlled. The modest significance implies any intrinsic correlation is weak and should be interpreted cautiously.

If this weak trend reflects genuine spectral evolution, it can be interpreted within near- or super-Eddington accretion frameworks. Increasing mass accretion rates drive radiatively launched winds that modify the effective photosphere of the flow. Enhanced reprocessing in the wind or funnel increases spectral curvature, producing progressively softer observed spectra as luminosity rises. In this picture, variations in fitted Γ primarily trace changes in continuum curvature rather than a simple power-law slope.

The observed positive L_X – Γ trend of softer spectra at higher luminosities has been reported for several ULXs including NGC 1313 ULX-1, Holmberg IX ULX-1, Holmberg II ULX-1, and NGC 5204 ULX-1, while others such as NGC 253 X-2 and NGC 1313 ULX-2 exhibit anticorrelations. This diversity demonstrates that luminosity–spectral-index relations are not universal across the ULX population.

NGC 4490 ULX-8 lies closer to the parameter space typically occupied by BH ULXs than to that associated with NS ULXs. With HRs $\text{HR} \approx 0.8$ –3 and photon indices $\Gamma \approx 0.9$ –2.7, it falls outside the harder spectral region preferentially occupied by NS ULXs, where magnetically channelled accretion produces characteristically hard continua (A. Grpide et al. 2021a). Instead, the spectral properties of ULX-8 are consistent with disc-dominated emission expected from super-critical disc and wind geometries (J. C. Gladstone & T. P. Roberts 2009; A. D. Sutton et al. 2013; P. Kaaret et al. 2017), favouring an interpretation in which the compact object is a stellar-mass BH.

6 CONCLUSIONS

We have presented a comprehensive X-ray spectral and variability study of the ULXs NGC 4490 ULX-8 using 14 *Chandra*, 6 *XMM-Newton*, and 19 selected *Swift*-XRT observations obtained between 2000 and 2024. Our main conclusions are as follows:

(i) **Spectral properties and luminosity range:** Across all epochs, the source spectra are adequately described by absorbed power-law and multicolour disc blackbody models. The inferred unabsorbed luminosities span $\sim (3$ – $20) \times 10^{39}$ erg s $^{-1}$ for power-law fits and $\sim (2$ – $5) \times 10^{39}$ erg s $^{-1}$ for disc-dominated fits, firmly placing ULX-8 in the ultraluminous regime.

(ii) **Variability behaviour:** ULX-8 exhibits significant variability over the ~ 24 -yr observational baseline, while remaining comparatively stable within individual observations. On week-month time-scales, variability factors of 3.73 ± 1.04 and 2.59 ± 1.37 are measured from regularly sampled *Chandra* and *Swift*-XRT data, respectively, placing the source among persistent to moderately variable ULXs. No robust short-term periodicities are

detected, although mild fractional variability is present in a small subset of observations.

(iii) **Spectral state and accretion regime:** The X-ray spectra across all epochs are characterized by a smooth, single curved continuum peaking at $\sim 1\text{--}2$ keV, with no persistent hard excess or distinct soft component. Combined with the observed luminosity range and moderate variability, these properties are consistent with the broadened-disc ultraluminous regime. No evidence is found for transitions between canonical hard and soft spectral states.

(iv) **Spectral correlations:** A positive $L_X\text{--}\Gamma$ correlation is observed across all epochs when N_H is allowed to vary freely, accompanied by a strong $\Gamma\text{--}N_H$ correlation. When N_H is tied across epochs, a weak but statistically significant positive $L_X\text{--}\Gamma$ trend persists for the majority of epochs, indicating that absorption-related effects influence but do not fully account for the observed spectral variability.

(v) **Disc temperature and compact-object constraints:** The $L_X\text{--}T_{\text{in}}$ relation yields a positive but weakly constrained slope due to substantial temperature uncertainties, remaining compatible with both thin-disc and slim-disc scalings. Disc-based mass estimates derived from the highest quality *XMM-Newton* spectra are inherently model-dependent, but yield illustrative values spanning $\sim 17\text{--}81 M_\odot$, depending on the assumed BH spin.

(vi) **Nature of the compact object:** The spectral hardness and photon index of ULX-8 place it outside the parameter space typically occupied by NS ULXs. Combined with the mass estimates and the observed spectral shape, the source is consistent with a stellar-mass BH accretor operating in the broadened-disc ultraluminous regime operating at or near the Eddington limit.

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DATA AVAILABILITY

All the data sets described in Section 2 of this paper are publicly available. The *XMM-Newton* and *Swift*-XRT data can be downloaded from NASA's High Energy Astrophysics Science Archive Research Center (HEASARC; <https://heasarc.gsfc.nasa.gov/docs/archive.html>). *XMM-Newton*'s data can also be accessed from ESA's *XMM-Newton* Science Archive (XSA; <https://www.cosmos.esa.int/web/xmm-newton/xsa>). The *Chandra* data are available from the *Chandra* Data Archive (<https://asc.harvard.edu/cda/>).

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APPENDIX A: BEST-FITTING SPECTRA

The best-fitting spectra for the 14 *Chandra* observations are shown in Fig. A1 and those for the 7 *XMM-Newton* observations are shown in Fig. A2.

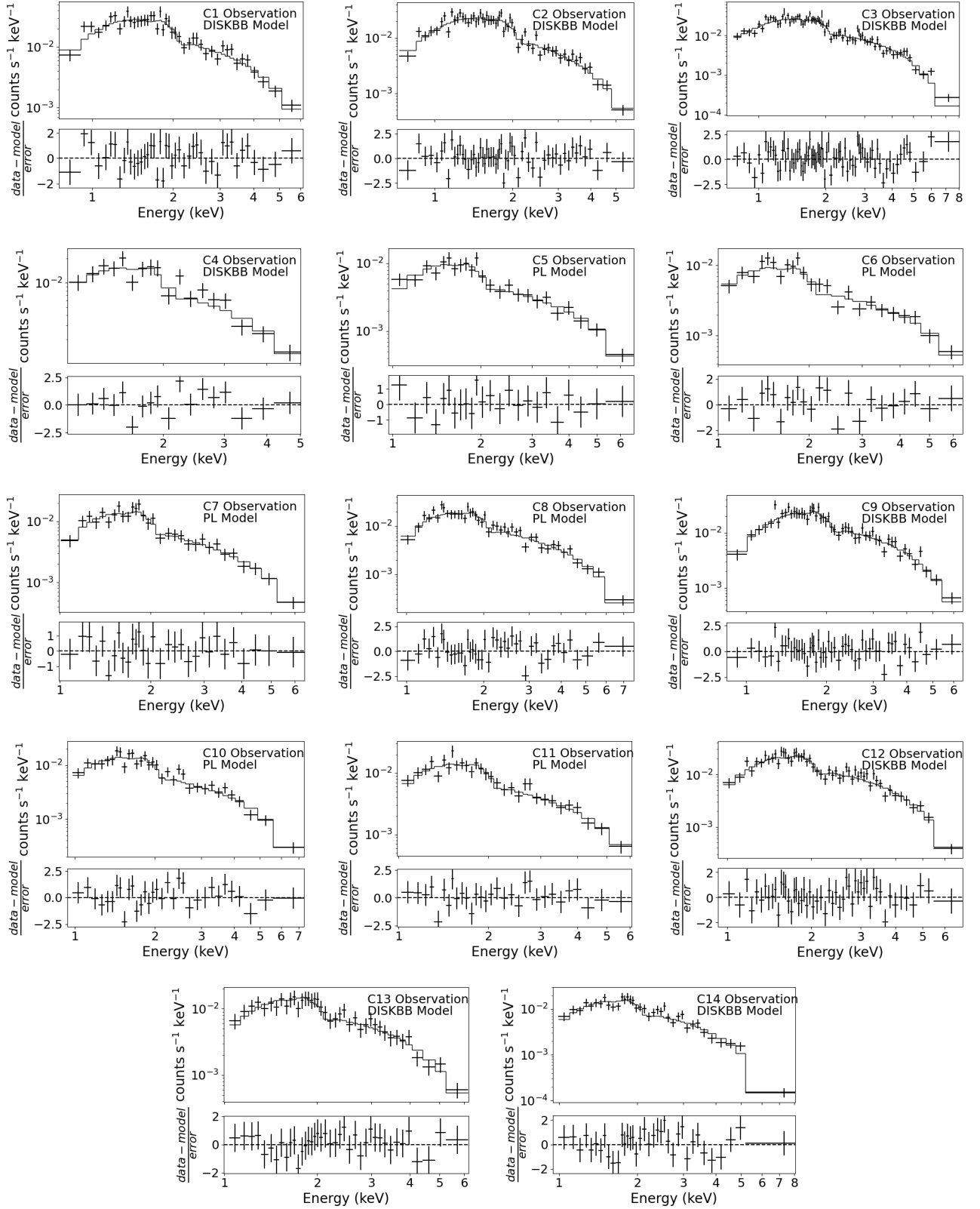


Figure A1. Best-fitting spectra of all *Chandra* observations of NGC 4490 ULX-8 obtained with the ACIS instrument. Each panel shows the observed spectrum (data points with error bars) fitted with best fit of either a multicolour disc blackbody (DISKBB) or a power-law (PL) model, along with the corresponding residuals in the lower sub-panel.

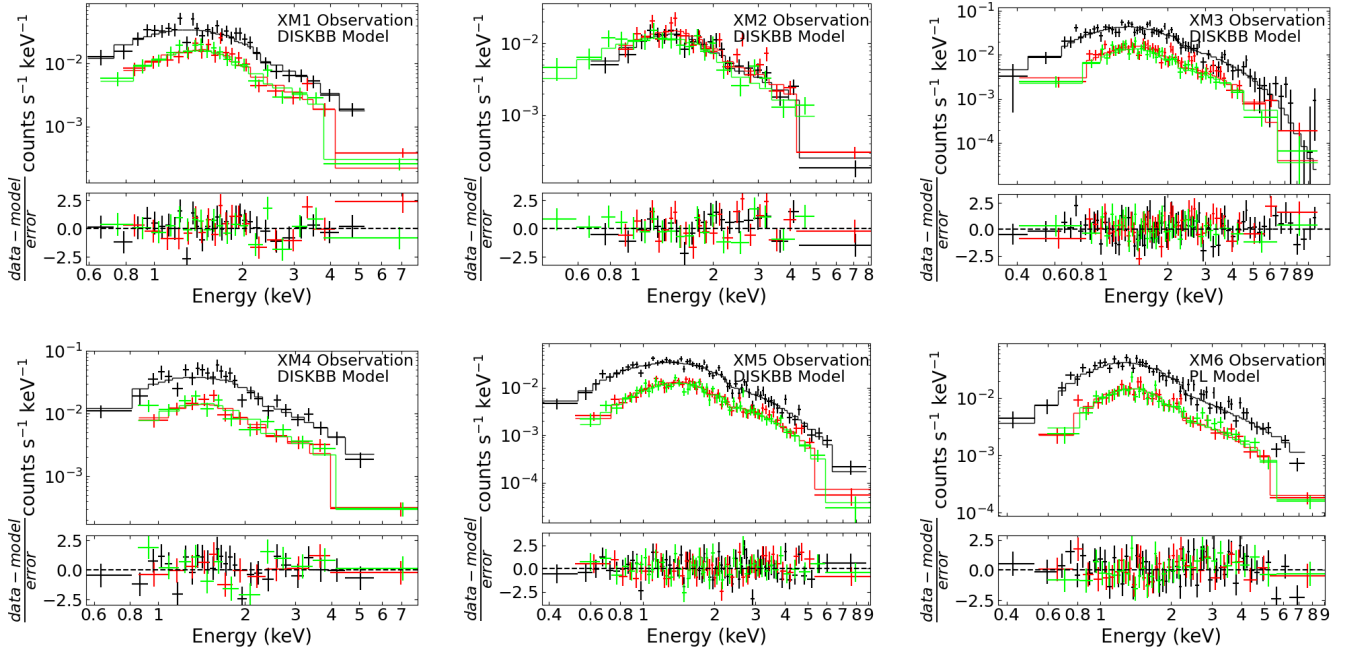


Figure A2. Best-fitting spectra of NGC 4490 ULX-8 from *XMM-Newton* observations. Data from the EPIC-pn, MOS1, and MOS2 detectors are shown in black, red, and green, respectively. Each panel shows the observed spectrum (data points with error bars) fitted with best fit of either a multicolour disc blackbody (DISKBB) or a power-law (PL) model, along with the corresponding residuals in the lower sub-panel.

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