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# An X-ray Study of the disc in GX339-4

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We present a detailed investigation into the X-ray emission from *GX339-4*. Using all data for *GX339-4* in the Rossi X-ray Timing Explorer (RXTE) archive, we perform a consistent analysis of the X-ray emission over a 10 year baseline. We will show our results into the emission from and evolution of the disc and its properties during outbursts. Using this thorough analysis, we focus especially on the disc temperature and disc fraction, and how these are related to relativistic ejection events. We also present a Disc Fraction Luminosity Diagram for *GX339-4*.

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## 1. Introduction

Continual monitoring of the radio sky will detect the short timescale as well as the longer timescale variation of the radio emission from X-ray binaries (XRBs). The galactic XRBs will be among the brightest transient sources in the galactic plane of the Milky Way. To understand the changes within the XRB system during an outburst (long timescale variation), understanding both the radio and the X-ray emission is vital. The X-ray spectrum shows how the accretion disc's nature changes during the outburst. Combining this with the radio spectrum, we can investigate the jet. We therefore present the preliminary results from this study of the X-ray emission from GX339-4.

GX339-4 was discovered in 1973 by the *OSO-7* satellite, and has been classed as a low-mass X-ray binary as the optical emission from the companion star has not yet been detected. The spectral and temporal characteristics of its electromagnetic emission are similar to other black-hole binaries. The X-ray binary is also a weak but persistent radio source with a flat spectrum and typical fluxes between 5–10 mJy at centimetre wavelengths. The X-ray flux regularly varies over 4–5 orders of magnitude. This regular and high variability makes GX339-4 a very interesting source to study to further our knowledge about X-ray binaries.

## 2. Data Reduction

The *RXTE* telescope has been observing the X-ray sky for the past 11 years, resulting in a long baseline to investigate the outbursts of GX339-4. We used all the public data in the *RXTE* Archive at the time. The data were re-reduced to standardise the data-products for all observations rather than using the standard data-products. The data reduction and spectral analysis was scripted for consistency.

We use data from both *HEXTE* as well as *PCA*. The high energy sensitivity from *HEXTE* allows the high-energy power-law slope to be more accurately constrained, which assists greatly when investigating the disc, most of whose emission falls below the sensitivity bounds of the *PCA*. There are four *PCA* detectors, however only one (*PCU-2*) has been on for the entire length of the mission, and so for consistency we use that.

Our initial investigation was into the presence or absence of an iron line. We find that in any observation which contains fewer than $10^4$ counts no line could be determined from the spectrum, whatever state GX339-4 is in at the time. We therefore exclude all observations which contain fewer than $10^4$ background-subtracted counts. The excluded observations occur at all points throughout the outbursts, with, of course, a concentration in the inter-outburst periods. The low-luminosity observations which have low counts fall into the "stalks" of the Hardness-Intensity Diagrams and Disc Fraction Luminosity Diagrams. As we are interested in the disc properties and the ejection events, excluding these observations is unlikely to bias our conclusions. The lightcurve of *GX339* (see Fig. 1) shows that there have been at least four outbursts during the monitoring by *RXTE*. The middle two have the most coverage, and so some of the analysis concentrates on these alone.

We fit the spectra in XSPEC, using *PCA* absolute channel number 7 to an upper energy of 25 keV and *HEXTE* 20 – 250 keV. We use a channel rather than an energetic cut-off for the *PCA* as this allows us to have a well calibrated spectrum to the lowest possible energies; the energies corresponding to channel number changed throughout the mission and all channels greater than 6

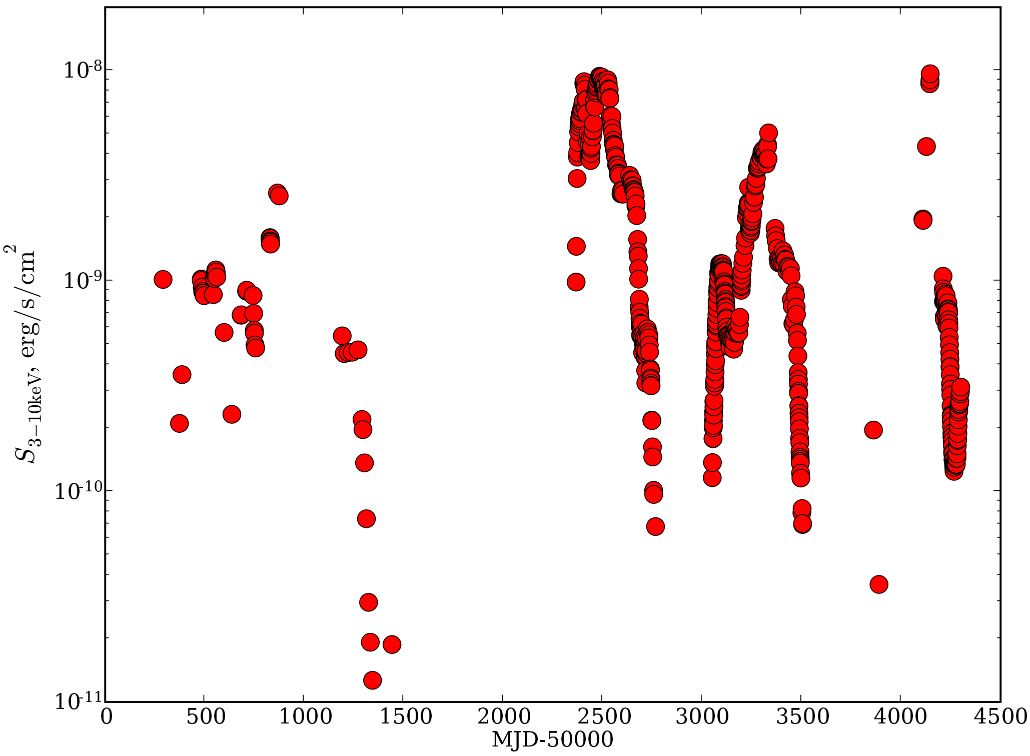


**Figure 1:** The light curve of *GX339-4* over the 11 years of *RXTE* observations.

are well calibrated. The galactic absorption was fixed to $0.6 \times 10^{22}$ cm$^{-2}$ [7]. To investigate the state of *GX339-4* we fit three types of model: POWERLAW, BROKEN POWERLAW and POWERLAW + DISC. A version of each model also having a Gaussian line at fixed energy of 6.4 keV was fitted.

The best fitting model was selected on $\chi^2$ terms, and an F-test was done to see if the line was significant. We create a Hardness-Intensity Diagram (HID) [3] to show the evolution in spectral state during the outbursts (see Fig 2). The best fitting model is also shown in the HID, all observations when the source was in the soft state have a disc component, and most of the others are a broken powerlaw. Only a few are an un-broken powerlaw. There are some observations in the intermediate and hard states (see Fig 3) where a disc appears to be required. However the disc temperature in these observations is very high, and so we do not consider that a model with a disc is appropriate.

## 3. Disc Evolution

By allowing the option of a multi-colour disc model in the spectral fitting we are able to investigate the evolution of the disc parameters through the outburst. It is expected that during an outburst the disc moves closer to the X-ray binary, and so becomes hotter and brighter. All four outbursts are shown in Fig.3, however the variation in disc temperature is very smooth with the total flux from the source. The disc temperature is high at the beginning of the outburst and then decays to around 60 per cent of the initial value by the time *GX339-4* re-enters the hard state. Further

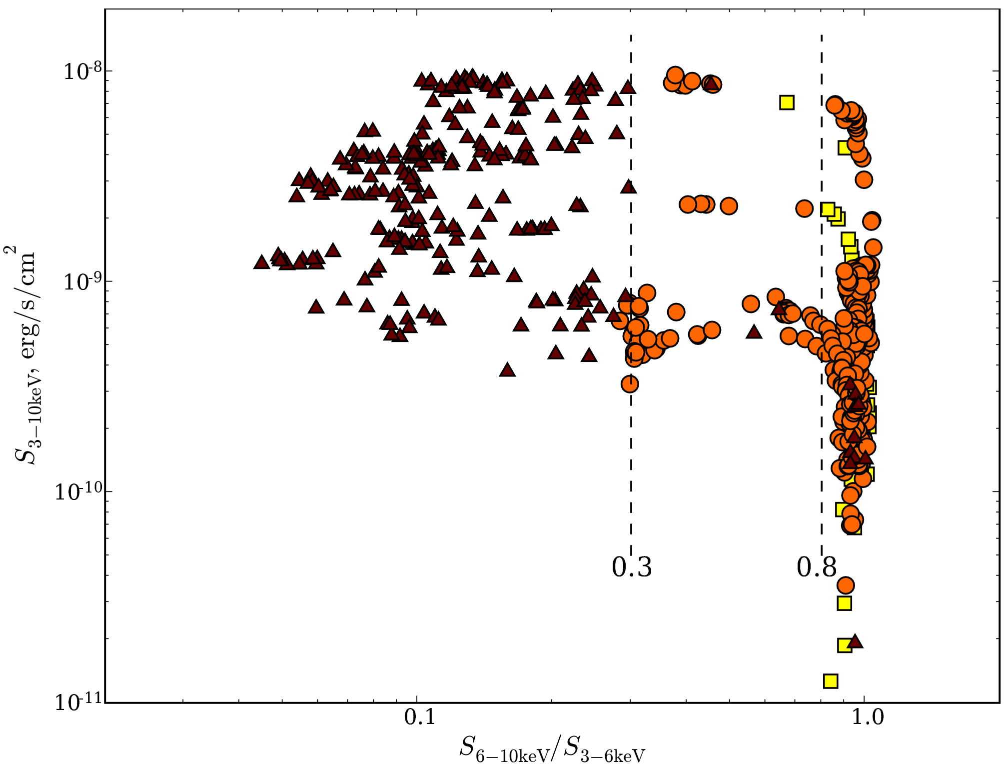


**Figure 2:** The HID for the outbursts from *GX339-4*. The different symbols correspond to the type of model which resulted in the best fit. Squares are the powerlaw, circles are the broken powerlaw and triangles are the powerlaw+disc models. The dashed lines at 0.3 and 0.8 show the transition from soft to intermediate to hard state used in this analysis.

investigations into the evolution of the disc temperature and other properties are beyond the scope of these proceedings and will be covered elsewhere.

## 4. Disc Fraction Luminosity Diagram (DFLD)

In recent years there has been a large amount of activity to compare black holes of different masses and to see if they are similar in their properties, and, if they are, to see how those properties scale with the black hole mass. The "fundamental plane" of black hole activity [2, 6] shows that the radio and X-ray luminosities of black holes ranging from XRBs to Active Galactic Nuclei (AGN) fall on the same relation when scaled by their mass.

For further comparisons with AGN, a more general version of the HID can be constructed, as outlined in [5]. The working assumption was that, if AGN are essentially larger versions of XRBs, then they should also have outbursts, but lasting for much longer than the months in XRBs. If a large enough population of AGN were to be observed at a single instance in time, and all those observations plotted on a single HID then it would be expected to see something similar to that shown in Fig. 2, as each AGN would be at a different stage through an outburst when the observation was taken [5]. Hence, studying a large population of AGN should, in principle, result in an HID which would look similar to that for XRBs if AGN also have outbursts.

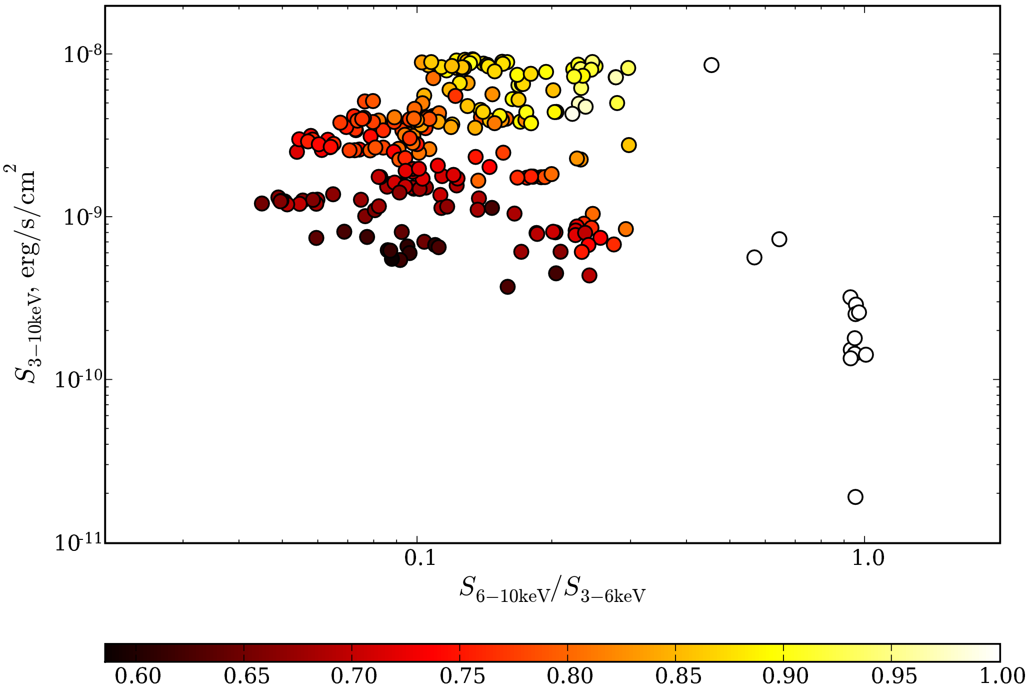


**Figure 3:** The HID for the models including a disc component. The colour scale shows the disc temperature, and has been truncated at 1 keV to exclude those observations in the intermediate and hard states.

The HID for an XRB basically shows the variation of the amount of disc emission during an outburst. The soft states have canonically been those where the disc emission is dominant, and the hard states where the non-thermal emission dominates. In XRBs both the disc and the powerlaw components are observed in the X-ray band. In AGN, however, the disc emission peaks in the UV band, and so using purely X-ray data for AGN would not shed much light on the state of the accretion disc.

Hence, a more general HID can be created (see [5]) by using the total luminosity and the "disc fraction" as calculated from

$$\mathrm{Disc\,Fraction} = \frac{L_{0.1-100\ \mathrm{keV,\ PL}}}{L_{0.001-100\ \mathrm{keV,\ Disc}} + L_{0.1-100\ \mathrm{kev,\ PL}}} \tag{4.1}$$

which characterises the relative strengths of the disc and power-law components and also remains finite if the disc component approaches zero. Although this is strictly the power-law fraction, or one minus the Disc Fraction, as we are interested in the strength of the disc emission when X-ray binaries and AGN traverse this diagram, we will refer to the quantity as the Disc Fraction.

To allow a direct comparison between the AGN and XRBs we construct a DFLD for *GX339-4*. We extract the powerlaw and unabsorbed disc fluxes from the model fits. In order to convert these to luminosities we take a distance of 8.5 kpc for *GX339-4*. The resulting plot is shown in Fig. 4, which is the first DFLD calculated for an X-ray binary. The overall shape of the DFLD for *GX339-4* is very similar to that shown for the population of AGN in Fig. 10 of Körding *et al.* [5].

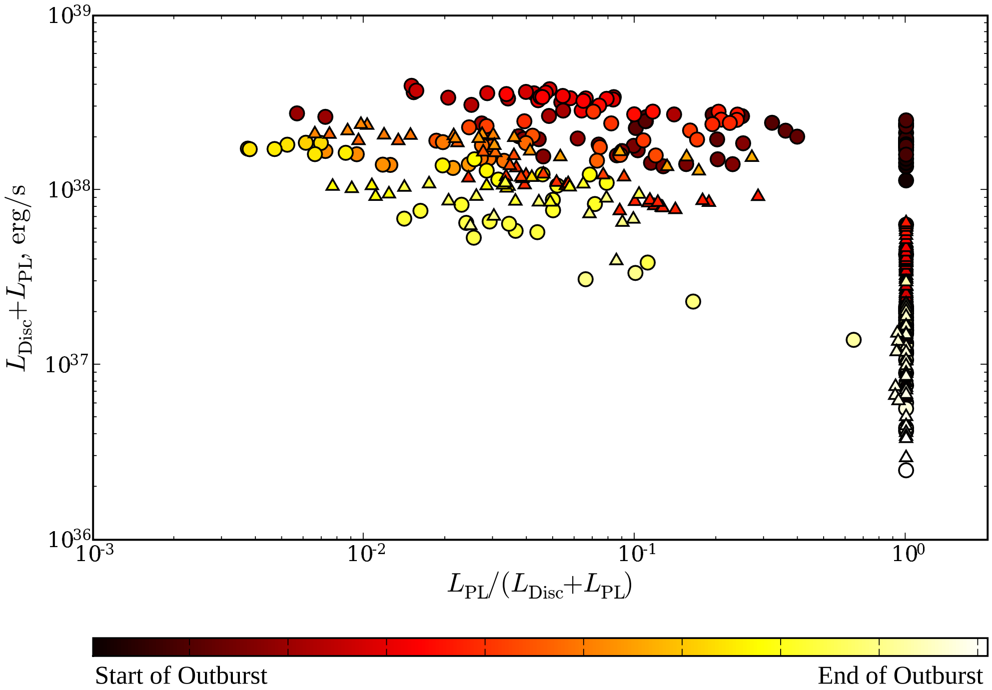


**Figure 4:** The Disc Fraction Luminosity Diagram for *GX339-4*. The colourscale is the date since the beginning of the outbursts, black being early and white being late in the outburst. Only the two outbursts with the best coverage are shown, the first one by circles, the second by triangles.

### 4.1 Radio/X-ray Correlations

To investigate correlations of the X-ray flux with the radio flux, we took the radio compilations of *GX339-4* presented in [1] and [4]. As the radio observations were not coordinated with the *RXTE* observations we match the two data-sets as best possible. If there is a radio observation within two days of an X-ray observation, then this radio observation is linked to the X-ray one. A two day overlap gave a reasonable number of X-ray observations which had corresponding radio flux values, such that a DFLD could be constructed showing the radio flux and spectral index variations through an outburst.

As can be seen in the left-hand panel of Fig. 5, the highest radio fluxes are observed at the top of the DFLD. There is a sharp drop in radio flux as *GX339-4* drops to the bottom of the DFLD and heads back to the hard state. There is also a possibility that the radio flux decreases as *GX339-4* moves across the top of the DFLD.

In the right-hand panel of Fig. 5 the change of the radio spectrum between the hard and soft states is clear. The stalk of the DFLD has a spectral index of $\alpha \sim 0.2$, whereas the soft state has a spectral index of $\alpha \sim -0.4 \rightarrow -0.6$. The spectral index was determined from $S_{\rm Radio} \propto \nu^{\alpha}$ over a range of frequencies, from 8.4 GHz to 0.84 GHz. Most observations were obtained at 8.4 and 4.8 GHz, for further details see [1] and [4]. This variation in spectral index has led to the following model of an outburst.

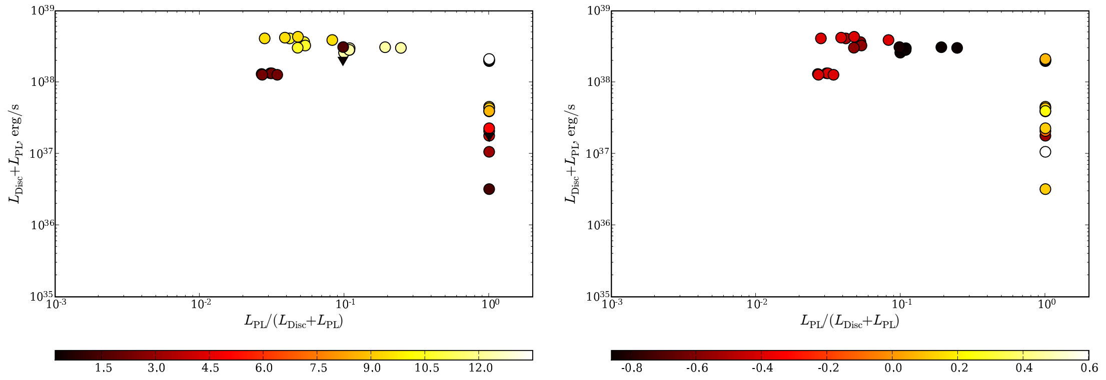


**Figure 5:** LEFT: The DFLD with the colourscale as the 8.4 GHz radio flux in mJy. RIGHT: The DFLD with the colourscale as the radio spectral index. Upper limits on radio fluxes are shown by inverted triangles.

In the quiescent (hard) state there is a steady radio-emitting jet, which brightens at the beginning of the outburst. The binary moves up the hard branch as a result of the increased luminosity. The disc begins to move inwards and the source moves towards the soft state. During this, the jet increases explosively with the peak in radio brightness and then ceases. Once fully in the soft state the disc fades as the accretion rate falls. Eventually the steady jet reforms and the disc fades entirely from the X-ray band as the source returns to the quiescent state.

## 5. Conclusions

We have performed a comprehensive and consistent analysis of the X-ray emission from *GX339-4*, concentrating on the information obtained from emission from the disc. Using the entire *RXTE* archive we have been able to study two of the outbursts in detail, as these contained most of the observations (446/606). We have created a Disc-Fraction Luminosity Diagram for all the outbursts of *GX339-4* observed by *RXTE* and linked it to the published radio flux measurements and compared it qualitatively to that for AGN.

Radio telescopes monitoring X-ray transients, like *GX339-4*, in combination with satellites like *RXTE* will be vital to the further study of these sources. Triggering from X-ray to Radio telescopes and vice-versa with *LOFAR*, *MWA* and *LWA* as well as the next generation of X-ray all sky monitors will enable the tracking of spectral changes in real time across a large frequency range.

These facilities will rapidly build up a large archive of data for the long term study of the accretion processes in XRBs and AGN.

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