Limits on spin determination from disc spectral fitting in GX 339–4

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13 April 2010

ABSTRACT

We attempt to constrain the black hole spin in GX 339–4 from spectral fitting of disc dominated data using RXTE spectra from the three most recent outbursts. We use the best current models for the disc emission, including full radiative transfer through the photosphere rather than assuming that the intrinsic emission from each radius has a (colour temperature corrected) blackbody spectrum. The results strongly depend on the poorly known binary system parameters, but we find a strict upper limit of $a_* < 0.9$ for any distance greater than 6 kpc, assuming that the orbital inclination is the same as that of the inner disc. By contrast, the higher spin of $0.935 \pm 0.01$ (statistical) $\pm 0.01$ (systematic) claimed from fitting the iron line profile in this object requires that the inner disc is misaligned by over 20 degrees from the orbital inclination. While some of these datasets are distorted by instrumental pileup, the same spin/inclination constraints are derived from data which are not piled up, so there is a real conflict between the two techniques to measure spin. We argue that the disc spectral fits are more likely to be robust hence that there are still issues to be understood in the iron line profile.

Key words: accretion, accretion discs, black hole physics, relativity, X-rays: binaries

1 INTRODUCTION

An astrophysical black hole (BH) can be entirely described by two parameters in general relativity, its mass $M$ and a dimensionless spin, $a_*$, which is 0 for a non-rotating Schwarzschild BH and 0.998 for a maximal Kerr BH. Unlike mass, spin only leaves an imprint on the spacetime very close to the event horizon, so it is much more difficult to measure. Nonetheless, it is important to constrain because it is a fundamental parameter determining the structure of the spacetime around the BH. It sets the size-scale of the last stable orbit around the BH, from $6 - 1.23 R_g$ for $a_* = 0$ and 0.998, respectively, where $R_g = GM/c^2$. This determines the efficiency of conversion of mass to radiation for accreting objects, and may also determine the structure and power of relativistic jets. For BHs formed from stellar collapse then the resulting spin gives insight into the (poorly understood) supernovae event (Gammie, Shapiro & McKinney 2004) and its gravitational wave signature.

Currently there are only two methods which can be used to determine spin from accreting BHs (see Reynolds & Fabian 2008; McClintock & Remillard 2006). The first uses the luminosity and temperature of the optically thick, geometrically thin accretion disc to measure the emitting area of the inner disc, and hence its radius. This assumes that the dissipation follows that of the relativistic stress-free inner boundary condition (Novikov & Thorne 1973), an assumption which is now strongly supported by recent fully relativistic MHD simulations of thin discs with self-consistent magnetic turbulence as the origin of stress (Shafee et al. 2008).

To use this method requires that we can observe the spectrum at energies close to the peak temperature, which limits this method to stellar mass BH binaries (hereafter BHBs), as AGN discs typically peak in the unobservable far UV. Additionally, the source distance, and disc inclination (assumed to be the same as that of the binary) must be constrained, as these are necessary to transform the observed disc flux into luminosity. Similarly, the BH mass is required to convert the resulting size scale into gravitational radii. Thus this technique can only be used on a small subset of systems for which this information is available. Further restrictions are that the systems should be dominated by the disc emission. The method can still be applied to data with an increasing fraction of emission in the power law tail, but with increasingly large uncertainties in reconstructing the
temperature and luminosity of the disc emission (Kubota et al. 2001; Kubota & Done 2004; Done & Kubota 2006; Steiner et al. 2009). A final restriction is that the source should not be too bright as the disc structure may change at luminosities approaching and exceeding the Eddington limit $L_{\text{Edd}}$.

The disc can puff up to become geometrically thick, advection and winds may become important, and the spectrum may also be increasingly distorted by low temperature Comptonization which can be difficult to distinguish from disc emission (e.g. GRS 1915+105; where Middleton et al. 2006 derive $\alpha_* \sim 0.7$ compared to $\alpha_* = 0.98$ from McClintock et al. 2006 due to differences in Comptonisation assumptions).

Within these limitations, the models including the full physics (stress-free inner boundary condition, relativistic smearing, and modelling the non-blackbody intrinsic emission from each radial annulus) are remarkably robust to changes in the disc vertical structure from different ad hoc stress prescriptions (Done & Davis 2008), and all the potential uncertainties act in the same direction which is for these models to overestimate the black hole spin (Gierliński & Done 2004; Done & Davis 2008).

The second method to measure spin uses the shape of the iron line produced by fluorescence in the X-ray illuminated accretion disc. The width of the line is set by the line emissivity, together with the strength of the gravitational field as this determines the velocity of the disc (hence the Doppler shift, beaming and time dilation) as well as gravitational redshift. All these parameters (inclination, inner disc radius in terms of gravitational radii and emissivity) can be constrained directly from spectral fitting, so this technique can be used much more widely than disc spectral fitting. Its only restrictions are that the disc is flat and in Keplerian rotation (which again becomes increasingly uncertain at luminosities approaching/exceeding Eddington) and that there are sufficient hard X-rays illuminating the disc to produce the iron line. Thus it can be used for both (sub-Eddington) AGNs and BHBs and requires no additional information about the distance and/or inclination of the system (Fabian et al. 1989; Fabian et al. 2000).

However, unlike the disc in the disc dominated spectra, the line is only a small feature on the total spectrum, which means it can be difficult to measure. The line sits on top of a reflected continuum, and the shape of both line and reflected continuum depend on ionisation of the material (Ross, Fabian & Young 2001), and the radial and vertical profile of this ionisation (Nayakshin, Kazanas & Kallman 2001; Done & Nayakshin 2007). Other key issues are the underlying continuum shape (which can be distorted by complex absorption: L. Miller et al. 2007; 2008) and distorting the intrinsic shape of the blue wing of the line from any absorption lines from ionised iron Kα (Done & Gierliński 2006; Done & Kubota 2006; Young et al. 2005).

Since we have two methods to measure spin it is obviously important to compare them. We would have increased confidence in both methods if they gave the same answer for the same object. However, the very different restrictions on the two techniques mean there is a very small set of objects where both can be used. Disc dominated spectra generally have too few photons at the high energies required to produce a strong iron fluorescence line. Similarly, disc spectral fitting cannot be used on spectra with a strong tail (carrying more than 25 per cent of the bolometric luminosity) as the uncertainties in reconstructing the intrinsic disc emission become too large (Kubota & Done 2004). Thus the two methods cannot be reliably compared using the same dataset (but see Miller et al. 2009 for an attempt at this), but they can be used on the same object for a BHB with well constrained system parameters which shows spectral transitions.

To date only three objects have good spin estimates from both methods, where ‘good’ is defined as derived from fits with the best currently available models i.e. BHspec for disc spectral fitting (Davis et al. 2005) and CDID for ionised reflection (Ross & Fabian 2005). The results are not encouraging. The spin estimates match well only for XTE J1550-564, are somewhat discrepant for 4U 1543-475, and are quite significantly different for GRO J1655-40 (see Section 6.3).

It is clearly important to expand the sample of objects for which this comparison can be made. GX 339–4 is one of the best studied BHBs in terms of iron line profile from three separate data sets, spanning a range of spectral states (Miller et al. 2004; 2006; 2008; Reis et al. 2008). Two of these datasets have issues with pileup, which distorts the line (Done & Díaz-Trigo 2010; Yamada et al. 2010), but results from the third dataset alone indicate a very high spin, with $r_{\text{in}} \sim 1.8$ or 2 depending on the detailed emissivity profile, requiring $\alpha_* = 0.96$ or 0.935 (Reis et al. 2008) and an inclination of $\sim 20^\circ$.

Here we apply the disc spectral fitting method and find that, despite the poorly known system parameters, such high spin is unlikely to match the observed temperature and luminosity of the disc dominated spectra from this source.
2.1 Distance, mass and inclination

Since the distance cannot be constrained by the companion star, it is instead estimated from the Na D absorption along the line of sight to the source. This gives $D \geq 6$ kpc, with distances as large as 15 kpc allowed, which would place GX 339−4 on the far side of the Galaxy (Hynes et al. 2004). Zdziarski et al. (2004) (hereafter Z04), show that the Na D absorption to GX 339−4 is similar to that seen towards OB stars in the galactic bulge, so suggest that it is more likely that GX 339−4 is at $D = 8$ kpc. Thus we take $6 < D < 15$ kpc as our range in distance, but this is probably too conservative as the companion star is likely to be seen at a distance of 6 kpc (Muñoz-Darias, Casares & Martinez-Pais 2008).

The mass function gives a lower limit to the mass of 5.3 $M_\odot$ (H03). However, this is too conservative considering the companion star. This must fill its Roche lobe, which is only possible with a long orbital period for a somewhat evolved star. Muñoz-Darias, et al. (2008) look in detail at these constraints, and argue for a stripped giant companion star with mass $M_2 \geq 0.166 M_\odot$, giving a solid lower limit to the black hole mass of 6.2 $M_\odot$. Conversely, the largest mass black hole in a low mass X-ray binary is GRS 1915+105 at $14 \pm 1 M_\odot$. Thus we consider the range 5.8 − 15 $M_\odot$ to be conservative, but note that 6.2 − 15 $M_\odot$ is more likely.

There is a strong constraint from the lack of eclipses that $i < 80^\circ$ (H03). However, the long orbital period and consequent large disc mean that this source almost certainly has a strong equatorial disc wind in its high luminosity states. These give strong ionised absorption lines when viewed at high inclinations ($i > 70^\circ$). There are ionised absorption features seen in GX 339−4, but these are much weaker than seen in the high inclination objects (Miller et al. 2004). This argues for an intermediate outer disc inclination, somewhat less than $70^\circ$, but not so much lower that the equatorial wind does not intercept the line of sight. Thus the outer disc (which should have the same inclination as the binary orbit) must have an inclination $\approx 50^\circ−70^\circ$. The upper limit of this range is similar to the hard limit on the orbital inclination of $i > 45^\circ$ that comes from putting the maximum BH mass of 15 $M_\odot$ into the H03 mass function with the minimum companion star mass of 0.166 (Muñoz-Darias et al. 2008).

However, it is the inner disc inclination which is important for determining spin, and this can be misaligned from the binary/outer disc if the BH spin is misaligned. There is a weak observational constraint on the inner disc inclination of $i < 70^\circ$ from the fact that there are no high frequency QPOs detected in this source (Schnittman, Miller & Homan 2006), and a strong requirement from the iron line fits at $i \sim 20^\circ$ (Miller et al. 2008). However, this would require a large misalignment angle of more than $25^\circ$ between the BH spin and orbit. Such large misalignments can only be produced from a very asymmetric supernovae, and the resultant large kick is likely to unbind the orbit (Fragos et al. 2010). Thus while we consider the range $20^\circ < i < 70^\circ$, the more likely lower limit is $45^\circ$ from the small misalignments required to form the binary (Fragos et al. 2010).

| $M$ ($M_\odot$) | $d$ (kpc) | $i$ (deg) | Reference |
|----------------|-----------|-----------|-----------|
| 5.8            | 6         | 20        | H03       |
| 10             | 8         | 60        | Z04       |
| 10             | 6         | 40        | GN06      |
| 15             | 6         | 45        | Max       |

Table 1. The parameter sets used in this paper. The abbreviations refer to papers referenced in the text and are explained in Section 2. The inclinations are mostly indicative, chosen to allow a wider limit range.

2.2 Parameter sets

From the ranges given above, we select some example system parameter sets in order to illustrate the impact on derived spin. Previous work on GX 339−4 by Gierliński & Newton (2006) argued for 10 $M_\odot$, $D = 6$ kpc and $i = 40^\circ$ (hereafter termed GN06), as this gave similar transition properties to other BHBs. Zdziarski et al. (2004) used 10 $M_\odot$, $D = 8$ kpc and $i = 60^\circ$ (hereafter termed Z04). The highest spin values will be found from the lowest $D/M$ so $M = 15 M_\odot$, $D = 6$ kpc and lowest inclination, set to the more likely limit of $45^\circ$ (hereafter termed Max). However, we also consider a parameter set with $i = 20^\circ$ for the minimum BH mass and distance of 5.8 $M_\odot$, $D = 6$ kpc (hereafter termed H03).

3 DATA ANALYSIS AND SELECTION OF DISC DOMINATED SPECTRA

GX 339−4 has been widely observed with NASA’s RXTE satellite since its launch in 1995, and shows multiple dramatic outbursts covering all spectral states (Remillard & McClintock 2006; Done, Gierliński & Kubota 2007, hereafter DGK07). We use data from the last three outbursts of GX 339−4, namely the 2002/2003, 2004 and 2007 outbursts, where hard to soft state transitions could be observed. Data reduction was done using the standard RXTE data analysis methods. We add a systematic uncertainty of 1% to all the PCA spectra, and fit from 3–20 keV.

We follow the approach of Done & Gierliński (2003) in fitting the spectra with a simple multicolour disc (diskbb) plus thermal Comptonization (thcomp), with a Gaussian line (gau, constrained in energy between 6–7 keV) and smeared absorption edge (smedge, constrained in energy between 7–9 keV) added to approximate the effects of reflection. The hydrogen column density was fixed at $N_H = 6 \times 10^{23}$ cm$^{-2}$ (Zdziarski et al. 2004). We use these results to make hardness-intensity diagrams, and select only disc dominated spectra for spectral fitting (defined as those with HR $\leq 0.2$, which corresponds to spectra where the disc contains more than 80 % of the total luminosity).

4 SIMPLE DISC MODELS

Within the limitations of disc spectral fitting discussed in the introduction, an indication of the black hole spin can be derived from fitting the very simplest disc model, diskbb (Mitsuda et al. 1984), to the data. To illustrate that these disc dominated spectra not only look like a disc, but vary like one too, we first use the simple diskbb fits above and plot
bolometric, unabsorbed disc flux from the models against temperature in Fig 1. Plainly the data are consistent with $L_{\text{disc}} \propto T_{\text{disc}}^4$ relation, as expected from a constant inner size scale set by the last stable orbit. This observation gives a foundation for the more physical disc models described in Section 5.

To use these data to derive the size of this inner radius is more challenging than simply converting flux to luminosity via the system parameters discussed in Section 2. The derived luminosity is also dependent on inclination through relativistic effects, with Doppler boosting amplifying the observed flux at high inclinations. These relativistic effects also change the observed temperature with Doppler blueshift dominating at high inclination while redshifts from time dilation and strong gravity dominate at lower inclinations. The effect on both temperature and luminosity is small at $i = 60^\circ$ for $a_* = 0$, but the much stronger relativistic effects at $a_* = 0.998$ mean that red and blueshifts approximately cancel at an inclination of $i = 75^\circ$ (Zhang et al. 1997).

We follow Gierliński & Done (2004) and correct the data for these relativistic distortions, to derive an 'intrinsic' temperature and luminosity for each parameter set assuming $a_* = 0$. We use the correction factors tabulated by Zhang et al. (1997), interpolated in $\cos i$ using a cubic. Figure 2 shows these corrected data for $a_* = 0$.

Even though the simple disc models are widely used as approximations, the true inner disc is much more complicated. The DISKBB models assumes a temperature distribution $T(r) \propto r^{-3/4}$, so does not incorporate the relativistic stress-free inner boundary condition. Similarly, each annulus of the disc does not emit a true blackbody. The continuum (free-free) absorption drops as a function of frequency, which means that the higher energy photons in each radius are unlikely to thermalise. The emission instead can be described as a modified blackbody, characterised by a colour temperature which is a factor $T_{\text{col}} = 1.6 - 2$ (Shimura & Takahara 1995) above the blackbody emission. We incorporate both these correction factors in the lines overlaid on Fig 2. (see Gierliński & Done 2004), for the expected size scale of 6$R_g$ for $a_* = 0$. These show that the derived spin will be dependent on the assumed system parameters. The system parameters of Z04 appear consistent with zero spin, while H03, GN06 and Max are progressively further from the $a_* = 0$ prediction, indicating higher spins.

### 5 A MORE PHYSICAL MODEL FOR DISC

Even after all the corrections to the disc spectrum, the assumption that the spectrum has a modified blackbody shape is still just an approximation to the full radiative transfer scenario. Photo-electric (bound-free) absorption from partially ionised metals becomes significant especially at high energy frequencies, where the free-free absorption drops. This effect is highlighted by the radiative transfer through the vertical structure of the disc, and while these spectral features are smeared by the special and general relativistic effect, they still result in a broader spectrum than predicted by the simpler models. We use the BHSPEC model by Davis et al. (2005) which includes stellar atmospheres-like calculations to calculate the vertical structure and radiative transfer of disc annuli, and incorporates the self-consistent relativistic radial dissipation profile (stress-free inner boundary condition for any $a_*$: Novikov & Thorne 1976) and fully relativistic transport to produce the observed spectrum.

This model is described by the physical parameters of mass, spin, distance, inclination and mass accretion rate, parameterised as $L/L_{\text{Edd}}$ (so the corresponding mass accretion rate depends on the black hole spin). Thus there is no effective temperature to use as input into the Comptonization for the seed photon energy. Instead we fix this at the best estimate of $f_{\text{col}} = 1.8$.

![Figure 1](image1.png) **Figure 1.** The bolometric disc flux versus the inner disc temperature from fitting DISKBB to the disc dominated spectra from GX 339-4. The solid line illustrates the $T_{\text{disc}}^4$ relation and the red dots indicate the 9 spectra chosen for simultaneous fitting in Section 5.1.

![Figure 2](image2.png) **Figure 2.** The $L - T^4$ relation in GX 339-4 with the different system parameter sets detailed in Table 1. The lines refer to $f_{\text{col}}$ values of 1.6, 1.8 and 2.0 for $a_* = 0$. The solid line marks the best estimate of $f_{\text{col}} = 1.8$. 

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fit inner disc temperature derived from the previous diskbb models.

The large number of datasets means that simultaneous fitting for $\alpha_*$ across all the spectra is not feasible. Instead, we fit each spectrum separately with $\alpha_*$ fixed at 0, then average all the individual $\chi^2$. We then repeat this for $\alpha_*$ fixed at 0.1, 0.2 etc up to 0.998. Fig 3 shows these $\chi^2$ versus spin for the four parameter sets. The plots show a rough position for the minimum $\chi^2$ i.e. best fit spin for each particular set of parameters. As is quite clear from Figure 3, the best-fit values for $\alpha_*$ vary significantly with the different parameter sets. Z04 gives a best fit of $\alpha_*=0$ as indicated by the simple diskbb fits above, while H03, GN06 and Max have a best fit of $\sim 0.7, 0.8$ and 0.9, respectively. All these best fits have very similar $\chi^2$, so these very different spin values obtained from the very different parameter sets cannot be distinguished by spectral fitting.

5.1 Simultaneous spectral fitting

After fitting all the spectra individually, we chose 9 spectra which together represent the full scale of the flux (marked by the red points in Figure 1). These 9 spectra were then fitted together simultaneously with the four different sets of system parameters. However, this time the spin parameter $\alpha_*$ was tied between the datasets, and fit explicitly. This allows us to explore the complex effects of inclination directly, by deriving spin for three different inclinations, 20°, 40° and 60°. The results are plotted in Figure 3 and the unfolded spectra is plotted with the simple diskbb+thCompm model at different luminosities in Figure 4.

The inclinations are illustrated with different colours for easy comparison; the smallest inclination angle (20°) is marked with green, 40° with red and the largest angle, 60°, with blue. As is clear from all the fits, increasing inclination angle decreases the spin. This simultaneous spectral fitting gives the same results as the multiple independent fits for the same inclination angle, but gives higher resolution around the spin value e.g. for H03 the minimum appears rather shallow, extending from 0.6–0.8, whereas in the simultaneous fits it is clear that for $i=20^\circ$ then $\alpha_* = 0.7$ is the best fit. For Max, an inclination of 20° gives $\chi^2 > 400$ so is not included in the plot. This is because for such a low inclination, this would imply an emitting area smaller than that from maximal spin. Similarly, $i = 60^\circ$ is not shown on H03 as this would imply such a large emission area as to require retrograde spin.

Assuming the inner disc inclination is the same as the orbital inclination, then the lower limit of $\sim 45^\circ$ implies that $\alpha_* < 0.9$ for any reasonable mass ($< 15 M_\odot$) and distance (> 6 kpc). Any lower mass and/or larger distance and/or higher inclination will give lower spin.

6 DISCUSSION

6.1 Spin from disc spectral fitting

There is a hard upper limit on spin of $\alpha_* < 0.9$ from the disc spectral fitting, assuming that the inner disc inclination is the same as that of the orbit. Our upper limit is very conservative as it is quite unlikely that the system parameters are all at their extreme values, and in fact a distance of 6 kpc is inconsistent with a 15 $M_\odot$ black hole. At 6 kpc the companion star must be towards the ‘minimum mass’ solution of Muñoz-Darias et al. (2008) in order to get below the observed r-band magnitude limit of 21.4 (Zdziarski et al. 2004; corrected from Shahbaz et al. 2001). Such a star has a low mass transfer rate, yet a large black hole requires a high mass transfer rate to keep the disc close to the borderline between quiescent and transient in order to trigger the multiple outbursts (Muñoz-Darias et al. 2008).

| Parameter set | $i$ (°) | $\alpha_*$       | $\chi^2$ vs 297 d.o.f. |
|---------------|---------|-------------------|------------------------|
| H03           | 20      | 0.711 $^{+0.017}_{-0.013}$ | 246.62                 |
| M= 5.8 $M_\odot$ | 40      | 0.287 $^{+0.028}_{-0.027}$ | 255.43                 |
| D= 6 kpc      | 60      | 0.000 (hard limit)   | 1014.74                |
| Z04           | 20      | 0.874 $^{+0.010}_{-0.002}$ | 243.75                 |
| M= 10 $M_\odot$ | 40      | 0.540 $^{+0.012}_{-0.006}$ | 253.85                 |
| D= 8 kpc      | 60      | 0.000 (hard limit)   | 297.10                 |
| GN06          | 20      | 0.985 $^{+0.014}_{-0.015}$ | 302.49                 |
| M= 10 $M_\odot$ | 40      | 0.780 $^{+0.013}_{-0.024}$ | 251.35                 |
| D= 6 kpc      | 60      | 0.352 $^{+0.005}_{-0.023}$ | 291.23                 |
| Max           | 20      | 0.998 (hard limit)   | 37480.59               |
| M= 15 $M_\odot$ | 40      | 0.946 $^{+0.005}_{-0.004}$ | 244.15                 |
| D= 6 kpc      | 60      | 0.710 $^{+0.019}_{-0.010}$ | 287.64                 |

Table 2. The results for the simultaneous spectral fitting showing the best-fit $\alpha_*$ values with different inclinations.
6.2 Spin from the iron line fits

There are three independent data sets for GX 339−4 where the line profile has been modelled in detail (Miller et al. 2004; 2006; 2008; 2009; Reis et al. 2008; 2009). We take the most recent determinations, as these use the best current reflection models for black hole binary discs (Ross & Fabian 2007). The low/hard state XMM-Newton MOS data give an inner radius of \( r_{\text{in}} = 2.04^{+0.07}_{-0.02} \) and inclination \( i = 20.0_{-1.3}^{+0.2} \) (no upper limit given) with emissivity \( 3.15 \pm 0.15 \) (Reis et al. 2008). Suzaku observations of an intermediate state give \( r_{\text{in}} = 3.90^{+0.24}_{-0.29} \) (i.e. spin of 0.89 ± 0.04), inclination \( i = 18^\circ \pm 1^\circ \) (no upper limit given) with emissivity 3.0 ± 0.1 (Miller et al. 2008). Very high state XMM-Newton burst mode PN data give a consistent inner radius and inclination of \( r_{\text{in}} = 2.92_{-0.06}^{+0.07} \) and \( i = 20.0_{-0.3}^{+0.2} \) (no upper limit given). However, this requires a broken power law emissivity which changes from 3 to 7 in brackets at \( r = 6 \) (Reis et al. 2008).

However, two of these datasets have been challenged as being affected by instrumental pileup. This clearly affects the line determined from the XMM-Newton MOS low/hard state data, as the simultaneous PN timing mode (which can handle much higher count rates without pileup) data also affected a much narrower line (Done & Diaz Trigo 2009). Similarly the intermediate state Suzaku observation may also be affected by pileup (Yamada et al. 2009). However, the PN burst mode very high state data are not affected by this. These give an equivalent spin of \( 0.942_{-0.004}^{+0.005} \) for \( i = 18^\circ \pm 1^\circ \) and central emissivity of \( \sim 7 \).

6.3 Comparison of spin from disc fitting and Fe line profile

Thus there is a clear mismatch between the parameters derived from the iron line and those derived from disc spectral fitting in GX 339−4, even after excluding piled up data. The only possible way to make the two consistent are if the inner disc is seen at low inclination, so that it is misaligned from the binary orbit. This would also make it consistent with the low inclination of \( 18^\circ \pm 1^\circ \) derived from the iron line fits. However, such a large misalignment could only come about from a very asymmetric supernovae, but the consequent natal kick is most likely to unbind the black hole from its binary companion, disrupting the system entirely (Fragos et al. 2010). This high spin is also inconsistent with the natal spins predicted from supernovae collapse models (Gammie et al. 2004), though these are poorly understood. While accretion does act to spin up the black hole, a low mass companion star of \( \sim 1 M_\odot \) has insufficient mass to significantly increase the spin of a \( \sim 10 M_\odot \) black hole (King & Kolb 1999). We note that none of the spins derived from disc spectral fitting in low mass X-ray binaries are higher than 0.9 except perhaps GRB 1915+105, with \( a = 0.98 \) claimed by McClintock et al. (2006). However, this depends on details of model assumptions for the Comptonised spectrum, and can be as low as \( a_c \sim 0.7 \) (Middleton et al. 2006). It seems premature to use contested results from this pathological source to challenge the supernovae collapse models.
BHSPEC gives $\alpha_0 = 0.65 - 0.75$, with ionised reflection fits in Miller et al. (2009; Table 3) and disc fits in Shafee et al. (2006) and Davis et al. (2006).

This means that 2/4 objects (GX 339−4 in this paper and GRO J1655−40: Miller et al. 2009) for which this comparison can be performed give a significantly larger black hole spin from iron line fitting than from the disc spectral method. The remaining 2 objects are marginally consistent, though taking the uncertainties at face value means that formally the spins from 4U 1543-475 are also marginally inconsistent but in the opposite sense (disc fits give higher spin than the iron line).

Which method (if any!) should we trust? The disc spectrum is the dominant spectral component, and the derived disc parameters follow the predicted behaviour for a disc i.e. constant inner radius for changing mass accretion rate (Ebisawa et al. 1993; Kubota et al. 2001; Gierliński & Done 2004). By contrast, the iron line fits are to a small feature on the total spectrum (which may have a much more complex form than the typical fit of disc plus power law and its reflection) and often require a highly centrally concentrated line emissivity which is not consistent with the simplest expectations of disc illumination. Thus we argue that the disc spectral fitting model results are more likely to be robust.

### 7 CONCLUSIONS

We derive a hard upper limit for the spin of GX 339−4 of $\alpha < 0.9$ assuming that the inner disc inclination is the same as that of the binary orbit ($70^\circ < i < 45^\circ$). This is inconsistent with the spin of $0.94^{+0.05}_{-0.04}$ and inclination of $i = 18^\circ \pm 1^\circ$ derived from the (non-piled up) XMM-Newton burst mode very high state data (Reis et al. 2008). This high spin/low inclination derived from the iron line is already uncomfortably extreme compared to the lower spins predicted from supernovae collapse models, and the small misalignment angles between black hole spin and binary orbit predicted from binary formation models. While these are both potentially poorly understood, they are independent constraints and the iron line profile in GX 339−4 conflicts with both of them.

The iron line profile itself is in subtle conflict with the X-ray continuum as the reflection smearing parameters require that the illumination pattern is highly centrally concentrated (Miller et al. 2008; Reis et al. 2008). Yet the very high state spectral shape requires that much of the inner disc is covered by optically thick Comptonizing material, making it very difficult to see strong reflection from this material (Done & Kubota 2006).

Thus we argue that the spin/inclination/emissivity derived from the iron line profile are uncomfortably extreme. It seems far more likely to us that the more moderate spin implied by the disc spectral fitting results where the inner disc is more or less aligned with the binary orbit are giving a more robust answer. The inescapable corollary to this is that there are systematic effects affecting spin as derived from the iron line profile that are not yet understood. This is a crucial issue in applying the iron line models with confidence to derive spin in AGNs.

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