Pre-Viva Report on the Thesis of Ms. Yilmaz

Referee: Dominic Walton

I have now carefully reviewed the thesis submitted for the award of a PhD by Ms. Anastasia Yilmaz. After a couple of introductory chapters – the first on the astrophysics of black holes in X-ray binaries (BHXRBs) and the second on the facilities and techniques used during her work – the research presented is split into two main parts. The first is a spectral analysis of the extensive archival datasets on two BHXRBs (GRO J1655 and LMC X-3) obtained by RXTE in which various accretion disc models (both non-relativistic and relativistic) are compared in order to both explore the evolution of the accretion disc as e.g. the brightness of the source varies and to place constraints on the spin parameters for these black holes. The second focuses on exploring the properties of a new X-ray transient identified in the M51 galaxy, which is suggested to be related to an extreme sub-population of X-ray binaries referred to as ultraluminous X-ray sources (ULXs). The final chapter in the thesis presents a few general conclusions drawn from these two works.

Overall, it is clear from her submission that while she has been studying for her PhD Ms. Yilmaz has developed a broad set of technical skills. This includes the data reduction procedures for a wide variety of different X-ray observatories, spectral fitting of X-ray data (including through Bayesian procedures), some time series analysis and some imaging analysis. The two research chapters presented also certainly represent new and potentially interesting contributions to the broader scientific literature on black holes and X-ray binaries; the first of these has already been published in a high-impact journal (Monthly Notices of the Royal Astronomical Society).

The thesis is therefore likely acceptable for defence, but I think there are areas where it could still be improved if there is the opportunity to make corrections. I will summarise the main ones (as I see them) below, going chapter-by-chapter, in case there is such an opportunity. These issues (aside from ones purely related to formatting/text edits) will likely also form the basis for my main questions during the defence.

General Comments:

While the thesis is generally well written, there are occasions where the clarity of the writing could still be improved, if there is the opportunity to do so. There are also a set of typographical errors that I spotted (unsurprising in a document as extensive as this). These are generally minor, and are mostly one-off cases that are best highlighted via a marked up pdf (which I can provide after the defence if these corrections can be made). A few more systematic formatting issues are present throughout the document though:

- Whenever quotes are used, the opening quote mark is not correctly formatted. Remember that in latex opening quotes are inserted using the backtick key: `
- Section and equation references are often not correct. In particular, most of the equation references in the intro incorrectly point to equation 1.1.4. Presumably some of the section labels used have also been repeated between chapters, resulting in the section references becoming confused.
- In the reference list at the end of the document the journal names seem to be missing in most cases. This is likely due to using bibtex without the definitions for the journal abbreviations bibtex uses being added to the beginning of the master latex document.

Chapter 1 - Introduction:

- The first part, which focuses on the General Relativity relating to black holes, is extremely mathematical. In my view, this would benefit on occasion from some accompanying written explanation that describes the main physics at play in addition to presenting the relevant mathematical expressions. For example, what is the overall physical meaning of equation 1.1.1?
- A very useful addition to the part on XRBs would be an example spectrum that highlights all of the spectral components discussed and shows how they typically contribute to the overall observed spectrum, as well as a spectral comparison of the main accretion states highlighted. A short subsection on the quiescent state would also be a good addition to the set of accretion states discussed in section 1.1.3.
- State changes (e.g. hard → soft) are presented as though they are due to changes in the overall truncation radius of the disc. While this is a popular interpretation, there is still significant debate over what happens here, particularly over when the disc is significantly truncated away from the ISCO and where it is not. There are plenty of results, for example, that suggest the disc has already reached the ISCO during the brightest phases of the hard state, rather than remaining truncated at large distance throughout the hard state and then moving inwards through the state transition. Even if you have a preferred interpretation, it would be good to at least briefly acknowledge this debate here.
- The ULX section would really be improved by introducing some more logical structure to it via the use of sub-sections.
- In terms of methods to produce super-Eddington luminosities, I was surprised not to see geometric beaming by a thick accretion disc discussed. I think there are also several errors in the descriptions of the potential methods that are discussed: the diffusion timescale becoming longer than the accretion timescale does not allow the photons to escape, it does the opposite, and for a BH accretor these photons are instead carried over the event horizon; magnetic fields of $B \sim 10^{12-13}$ G are not really sufficient to suppress the electron scattering in neutron star accretors to a significant degree, magnetar-level fields ($B \sim 10^{14}$ G or more) are required; the scenario invoking relativistic beaming in a jet does not also require the presence of IMBHs (relativistic beaming has largely now been excluded anyway, owing to the X-ray ionised nebulae often seen around nearby ULXs).

Chapter 2 - Instruments & Techniques:

- When discussing the different facilities used, it would be useful to provide another couple of key specifications for them: their imaging and their spectral resolution.
- In some cases the type of detector being used by the instrument in question is explained, but in others this information is not provided; it would be good to be systematic in this regard. Similarly, the band passes for each instrument are not always provided (and are sometimes incorrect when they are).

Chapter 3 - GRO J1655 & LMC X-3:

- One of the main results this chapter focuses on is that the observations of GRO J1655 showing the highest disc temperatures also show a deviation away from the $L \propto T^4$ trend expected for a blackbody with a constant radius – which is seen from the lower-temperature observations – and that the use of the KYNBB with a variable inner radius allows these observations to recover back to this $L \propto T^4$ trend. This does not really make sense to me, though, as by varying the inner radius you are changing the size of the emitting region, and thus observation of a single $L \propto T^4$ trend would no longer be expected. Some further discussion of this issue would be important, I think.

- Related to this same issue, I wonder if the potential importance of using something like the SIMPL model for the coronal emission has been dismissed too quickly. The chapter notes briefly that this was explored, but often provided worse fits, and then the model is not discussed again. However, a potentially important advantage this model has is that it attempts to conserve photon number when introducing the high-energy continuum; if the coronal emission really is up-scattered flux from the disc (as the thesis proposes) then all of these photons were actually originally emitted by the disc, but were then 'removed' from this emission component and transferred to the coronal continuum. In this scenario, it is the pre-scattered disc flux that should be compared to its temperature to see if the disc is following $L \propto T^4$ or not (i.e. the disc flux should be calculated prior to the application of SIMPL, which one can do by putting the CFLUX component inside it). It is notable to me that all of the observations that show the high-temperature deviation away from $L \propto T^4$ all have large powerlaw fractions (based on the colour scheme used in Figure 3.4), and so any corrections to the disc flux in these cases could potentially be quite large. Even if the fits are a bit worse, did you check to see whether the disc would still follow $L \propto T^4$ even at high temperatures if the SIMPL model were used instead of the powerlaw?

- For the final spin constraints, the decision to focus only on the 3-6 keV band seems a bit of an odd choice to me. With such a limited bandpass you will not be able to properly constrain the powerlaw component, which then has the potential to impact the parameters inferred for the disc component. Furthermore, if you were to pick a band that is going to be the most impacted by any iron emission from disc reflection, it would be this one. I understand that observations where the iron emission is the strongest are unlikely to have been included in this analysis, but some iron emission is almost inevitable in a disc-corona geometry, and indeed can still be seen in the residuals shown in Figure 3.1 at least. Did you explore the impact this choice of narrow bandpass could have on your spin constraints at all? The issue relating to iron emission could be explored via a set of relatively straightforward simulations, at least.

Chapter 4 - M51 Transient:

- I am not sure why the discussion of this transient is so heavily focused on ULXs and super-Eddington accretion. The peak luminosity seen ($\sim 7.5 \times 10^{38}$ erg/s) comes close to, but does not exceed the ULX threshold, and is sub-Eddington for an $8\ M_{\odot}$ black hole (the peak of the mass distribution for BHXRBs; Ozel et al. 2010). Why is this not just a regular BHXRB transient that was seen to enter the Very High State (the high-luminosity variant of the steep powerlaw state) during its outburst? The steep spectra observed would seem consistent with this idea, but this possibility does not really seem to be discussed. It is possible, as noted, that the peak luminosity was missed and could have exceeded the ULX threshold, but this is speculative, and even if this were the case all of the available data would still be probing sub-Eddington accretion for a typical BHXRB.

- I was confused by a lot of the discussion relating to the timescale of the outburst from this M51 transient (mainly found in section 4.4.3). First, this seems to imply that the timescale seen here is too short compared to those seen from BHXRBs in our own Galaxy, but the recent, highly luminous outburst from V404 Cyg would easily fit within the constraints that can be placed on the duration of this M51 transient. The discussion goes on to claim that disc models fail to explain the short-lived outbursts from transient ULXs, but the disc instability model (typically invoked for the transient behaviour seen in regular LMXBs) seems to have no real problems explaining these systems (see Hameury & Lasota, 2020). The rest of the paragraph following the statement about disc models relates to magnetically-arrested (MAD) accretion discs, but I'm not sure that all thick discs necessarily need to be in the MAD regime, and in any case there are simulations showing that thick, super-Eddington discs can still be sustained in the MAD regime (Narayan et al. 2017). Finally, the claim that stronger fields result in shorter outbursts for neutron stars seems to be conflating accretion-powered outbursts and magnetar flares (based on the reference provided), but these are completely different physical processes.

- Unfortunately, there is a rather glaring error relating to the distance corresponding to $z = 0.5$ when discussing TDEs, which is definitely not ~43 Mpc. This does not just seem to be a simple typo, as this incorrect distance is then used to calculate luminosities, and those luminosities are then used to assess the plausibility of a TDE explanation.
- When searching for potential optical counterparts, was any effort made to try and register the *Chandra* astrometry to the *HST* imaging by matching 'field' sources? Doing so may allow you to refine the positioning of the *Chandra* error circle. Furthermore, the size of the error circle within which counterpart searches are conducted should be set by the combination of the statistical uncertainty on the X-ray source position and the uncertainty to which the relative *Chandra* vs *HST* astrometry can be registered (these would then typically be combined in quadrature). Taking this approach may allow you to refine the set of potential counterparts, as the overall error circle is almost certainly less than 2.5 arcsec. The properties of any remaining counterparts (magnitudes, separations from the X-ray position) should probably also be properly summarised somewhere (e.g. in a table if there are still a reasonable number).

Chapter 5 - Conclusions:

- One of the general conclusions drawn from the work on GRO J1655 and LMC X-3 is that systems that are similar on paper (similar mass, inclination) can show different spectral behaviour to each other despite accreting at the same rates, but I did not follow how this conclusion was reached, as the results presented in chapter 3 show very different accretion rates for these two systems (Figure 3.12). Can you elaborate?
- What are some of the potential future extensions to this work? It would be good for this chapter to have a dedicated subsection that briefly discusses this topic. Currently this is just limited to a few relatively generic sentences about future missions right at the end.