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Report on thesis of Mikolaj Grzedzielski

The thesis is an exploration of the instability that is predicted to occur in standard disc models when they become dominated by radiation pressure. This starts to become important in the inner regions of the disc at luminosities above a few percent of Eddington for stellar mass black holes, assuming that the disc heating scales with the total (gas+radiation) pressure. Supermassive black holes are dominated by radiation pressure out to much larger radii at the same luminosity. Thus this should be very important in all Active Galactic Nuclei (AGN), and most black hole binaries (BHB).

The thesis starts with an introduction to the properties of compact objects. This seemed quite uneven in places (see list of detailed comments at the end), but covers white dwarfs, neutron stars and black holes, together with how these are seen in X-ray binary systems.

Chapter 2 introduces accretion disc physics, and especially focuses on the properties of the local thermal instability in the disc. Oddly, since this is a thesis concerned with the effect of the radiation pressure instability, there is no discussion about how this propagates through the disc, turning from a local (single radius) thermal instability to a global change in disc structure via a thermal viscous instability. However, it does show that the local instability becomes severe for a standard disc (heating proportional to total pressure) when it becomes dominated by radiation pressure. There is the statement that these limit cycle variations 'receive confirmation in numerous sources', yet there are only 2 BHB (out of >20) which show behaviour which could be interpreted as limit cycles, and the other source cited, HLX-1, may well be showing the standard Hydrogen ionisation disc instability instead of the radiation pressure 'heartbeat'.

Chapter 3 looks at one of these limit cycle variability sources, IGR J17091, in more detail, using a time dependent disc code, GLADIS, to model the behaviour. This really needed more details of the code, in particular, how it compares to the other state of the art time-dependent disc code of Dubus et al (2001). This group make the case that their adaptive mesh approach is required in order to fully resolve the heating and cooling fronts, especially in AGN (Hameury et al 2009), so it is an important question as to whether GLADIS has such an adaptive grid. Including the wind is a very interesting extension to the code, especially as a wind is seen in IGR J17091 (King et al 2012). However, this is treated very briefly and not well explained. The section (very briefly) gives results on the code predictions for the heartbeat amplitude/period for different wind strengths, then tries to also match to the observed wind parameters (velocity, column and ionisation state) from King et al. This is a nice attempt to incorporate all these features together, but it was not clear whether this was indeed successful! It would also have been useful to also include a discussion about the wind features in the other limit cycle source, GRS 1915, but which have lower velocity (Neilsen et al 2009) despite the system being probably more luminous.

Chapter 4 is a more general treatment of the radiation pressure thermal-viscous instability, without winds, and how this scales with black hole mass. This uses a phenomenological heating prescription $P^{\mu}P_{gas}^{1-\mu}$, and the instability occurs only for $\mu>3/7$. This is interesting as current MRI simulations support the original $\mu=1$, though Merloni & Nayakshin (2006) give physical arguments for $\mu\sim0.5$. The data on AGN variability is more to do with stochastic 'flickering' rather than the periodic, highly deterministic lightcurve predicted here (fig 4.4), so there should have been more discussion on the applicability of these models to AGN (also in section 4.8.3). Nonetheless, without winds, this chapter shows that $\mu=0.5$-0.6 gives an interesting regime for stability/instability behaviour in all accreting objects.

Chapter 5 then applies this to HLX-1, the most likely intermediate mass black hole. The radiation pressure instability is an interesting possibility as the origin of its outbursts, though more discussion about alternative models would have been useful.

Chapter 6 is in my opinion by far the best work in the thesis, where the full opacities are included in the disc equations, to see if the increase in opacity with temperature around the iron bump can stabilise the disc as claimed by Jiang et al (2016). The calculations here show that this does decrease the amplitude of the limit cycle oscillations, but that the disc is still unstable. However, the results are clearly completely dependent on the choice of $\mu=0.56$. Some discussion about how this might change with other heating prescriptions would have been useful, as would an explicit comparison with Jiang's heating prescription.

The thesis then concludes with a summary. Regardless of the above critical comments, I generally conclude that the thesis meets the requirements of a PhD thesis in terms of contributing to the field as this includes work from 2 first author papers in refereed journals, as well as contributions to two other papers on the limit cycle instability. Therefore I conclude that the presented dissertation meets the formal requirements for a PhD theses and recommend admission of Mr Grzedzielski to the subsequent stages of the procedure, including the public defense.

Yours faithfully

Prof Chris Done