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The effect of X-ray irradiation on the time-dependent behaviour of accretion discs with stochastic perturbations

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ABSTRACT

The UV emission from X-ray binaries, is more likely to be produced by reprocessing of X-rays by the outer regions of an accretion disc. The structure of the outer disc may be altered due to the presence of X-ray irradiation and we discuss the physical regimes where this may occur and point out certain X-ray binaries where this effect may be important. The long-term X-ray variability of these sources is believed to be due to stochastic fluctuations in the outer disc, which propagate inwards giving rise to accretion rate variation in the X-ray-producing inner regions. The X-ray variability will induce structural variations in the outer disc which in turn may affect the inner accretion rate. To understand the qualitative behaviour of the disc in such a scenario, we adopt simplistic assumptions that the disc is fully ionized and is not warped. We develop and use a time-dependent global hydrodynamical code to study the effect of a sinusoidal accretion rate perturbation introduced at a specific radius. The response of the disc, especially the inner accretion rate, to such perturbations at different radii and with different time periods is shown. While we did not find any oscillatory or limit cycle behaviour, our results show that irradiation enhances the X-ray variability at time-scales corresponding to the viscous time-scales of the irradiated disc.

Key words: accretion, accretion discs – X-rays: binaries.

1 INTRODUCTION

Accretion discs are formed when matter from a companion star accretes on to a compact object which is usually a black hole or a neutron star (NS). The structure of such discs can be described in the 'α-disc' prescription (Shakura & Sunyaev 1973) which is often referred to as the standard accretion disc model. Most of the energy is released in the inner regions of the disc and is radiated at X-ray energies and hence these systems are observed as X-ray binaries. The flux generated and the temperature of the disc decreases with radius and hence the outer regions of the disc emit in UV or in the optical. However, there are couple of ways by which the outer region of the disc effects the X-ray emission from the inner parts. If the outer region is non-ionized, the disc becomes unstable. This hydrogen-ionized thermal instability leads to a long-term limit-cycle-like variability in the accretion rate (Cannizzo & Wheeler 1984). This is believed to be the origin of X-ray novae where an X-ray binary rises from quiescence on a time-scale of days and subsequently its luminosity decays in months time-scale. X-ray novae typically recur in time-scales of decades. For persistent X-ray binaries, the outer disc is perhaps always ionized and hence such systematic long-term variation is not seen. However, even for such persistent sources, the X-ray emission displays stochastic variability in a wide range of time-scales ranging from milliseconds to months. While the short-term variability should arise from the inner regions, it is the outer regions which are thought to be responsible for the long-term variation. A popular model for the long-term variability is the stochastic fluctuation model (Lyubarskii 1997) where fluctuations in different radii of the disc, induce accretion rate variations in the viscous time-scale of that radius. These accretion rate variations then propagate inwards and cause the observed long-term X-ray variability. Thus, the outer region of an X-ray disc effects the X-ray emission from the inner parts by regulating the accretion rate inflow into the inner region.

On the other hand, as noted and described by Cunningham (1976), the X-ray irradiation by the inner regions can affect the structure of the outer one. There have been several works to understand the structure and the resultant spectra of the outer regions in the presence of X-ray irradiation (e.g. Hayakawa 1981; Hoshi & Inoue 1988; Tuchman, Mineshige & Wheeler 1990; Ko & Kallman 1991; Dubus et al. 1999; Hubeny & Wickramasinghe 2004; Wickramasinghe & Hubeny 2005; Ritter 2008; Mescheryakov, Shakura & Suleimanov 2011). The reprocessed emission will be emitted in UV/optical and the spectra of such discs has been calculated and compared to observations (Hayakawa 1981; Vrtilek et al. 1990; Ritter 2008).

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