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Modelling the time lags in Black Hole X-Ray binaries

by

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Contents

List of Figures

List of Tables

Chapter 1

Introduction

A few years after Albert Einstein came up with the idea of the general theory of relativity, Karl Schwarzschild came up with the first modern solution to the general relativity theory that characterizes a black hole (Schwarzschild 1916). It would still take decades before "black holes" would be interpreted as a region of space that nothing can escape from in a paper by David Finkelstein (Finkelstein 1958). However, the idea of a "black hole" still only stayed a mathematical curiosity. It took until the discovery of a neutron star in 1967 (Hewish et al. 1968) for interest in gravitationally collapsed compact objects to increase. Just 5 years before that proof of X-ray sources outside our solar system had been found (Giacconi et al. 1962) which prompted the launch of a mission into space to look for X-ray sources. In this mission, several X-ray sources were observed, including Cygnus X-1. However, the observations showed that Cygnus X-1 had fluctuations in the X-ray of several times a second. Just a year later two different radio observatories independently located a star (HDE 226868) that was thought to be the source of the X-ray radiation. However, since it was found to be a super-giant star so it can't generate X-rays on its own. So it needed to have a companion that could heat up the hot gas to a high enough temperature to generate those X-rays (Kristian et al. 1971; Braes & Miley 1971). Then in 1972 this companion, the first Black Hole, was detected and identified independently by multiple researchers (Webster & Murdin 1972; Bolton 1972). It would still take until the following year for there to be consensus about it being a black hole. Researchers found fluctuations in the X-ray signal that could point to mass fluctuations in an accretion disk this combined with the fact that it can't be a neutron star due to its mass made them quite certain that Cygnus X-1 is a black hole (Rothschild et al. 1974; Shipman 1975).

This type of binary system where X-rays are emitted by the compact object component is called an X-ray Binary System or XRB for short. In such a binary system the star orbiting the compact object will be orbiting in such an orbit that the matter that the star is composed of will start to leave the surface and be attracted by the compact object. This creates an accretion disk as modeled by Shakura & Sunyaev (1973). This accretion is composed of hot plasma which emits X-rays as it gets closer and closer to the compact object. While the accretion of accretion matter inside the disk is known fairly well, the closer to the compact object the matter gets the less it is understood.

1.1 Theory

The x-ray light that is emitted by this accretion disk can tell us a lot about what is happening inside. Ever since the first detections of XRBs researchers have been able to notice variability of the light curve which can help to explain the physics in these regions. This light curve has been observed to have variability in the X-ray wavelengths on different time scales. This variability is not yet fully understood but researchers have crafted a theory to explain the properties of this variability on short-term timescales. Where they believe it to show a power-law component as well as the accretion disk giving a black body component emitting from itself. It would include reflective X-ray features which are generated by the light that is emitted by the disk as a power-law and is reprocessed. This X-ray power-law is generated by lower energy "seed" photons that are inversely Compton scattered by hot plasma, first described by Shapiro et al. (1976). These seed photons likely originate from the disk (Done et al. 2007). A region around the black hole that is less thin than the accretion disk is believed to be a "corona" which is composed of a hot, Compton scattering, region. This can be inferred from the fact that the X-ray reflection features show that at least tens of percent of the power-law components interact with the disk as the only assumption about its geometry.

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The variability of the light curve can then be quantified using a Fourier transform of the light curve at different energy bands. If then the cross-spectrum is then calculated between two different energy bands a lag can be found in the phase of the resulting spectrum. These "phase lags" can be converted to lags in time between the energy bands. This time lags can then be used to get a better understanding of the underlying physics of the XRB system.

1.3 Model

Using a proper model describing the emission processes and the time lags between them, the "spectral-timing" properties across a wide range of X-ray energies. These can be used to better understand the physics that produces these time lags. A recent model (Uttley & Malzac 2021) combines the ideas that the variability is driven by fluctuations of mass accretion through the disk and corona and that the disk provides "seed" photons for the Comptonization in the corona via black body radiation of the disk. These "seed" photons radiate to the corona where they cool the corona slightly due to the Comptonization of the photons. Fluctuations in the accretion then cause the corona to heat back up due to mass piling up in the disk. Because of this, the higher-energy photons lag behind the low-energy photons. Part of the photons that escape the black hole comes from the disk and thus are the lower energy "seed" photons. The higher energy photons are generated by the viscous dissipation of the mass fluctuations in the accretion disk near or inside the corona. Compton scattering inside the corona then causes the photons to get excited even more.

Chapter 2

Discussion

Chapter 3

Conclusion

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