Eclipse mapping of the accretion flow onto Neutron Stars

Introduction

Accreting neutron stars (NS) offer the chance to study the behavior of very dense matter in a regime impossible to replicate in a laboratory or, indeed, elsewhere in the universe. In NS binary systems, gas from a nearby companion star spirals towards the NS, forming an accretion disk in which lost gravitational potential energy is very efficiently converted into radiation through viscosity. The NS surface and innermost region of the disk glow brightly in X-rays, providing the chance to study the extreme region of strong gravity close to the compact object. However, for the foreseeable future we will lack the angular resolution to directly image this region and must instead *indirectly* infer the accretion geometry.

Since the gradient of the gravitational potential becomes steeper close to the NS, the material in the inner regions of the accretion flow is expected to 1) rotate more quickly and 2) emit a harder spectrum. Our project is to use eclipses by the companion star in highly inclined systems to achieve direct constraints on this fundamental geometry for the first time.

Goals

I spent the week of 13-17th October 2014 in Cambridge collaborating with Dr Matthew Middleton. We had already identified the NS binary system EXO 0748-676 as an ideal candidate for our study, since it displays eclipses in a number of high quality *XMM-Newton* observations and it's spectrum is dominated by a thermal accretion disk. This provides a chance to observe the effects of Doppler boosting from rapid rotation in the inner regions of the accretion flow. During the eclipse ingress, the companion star first obstructs Doppler boosted approaching disk material before obstructing receding disk material. During the egress, the companion first reveals the approaching material before revealing the receding material. Thus, we expect the flux to fall quickly then slowly in the ingress and rise quickly then slowly in the egress. Further to this, since the inner regions rotate faster *and* emit a harder spectrum, we expect this asymmetry between ingress and egress to be more pronounced for higher energy bands.

Our project thus has two main goals. First, we must determine if this asymmetry really can be observed with the data at our disposal in a model independent fashion. Secondly, we can then use theoretical modeling to map the radial emissivity and angular velocity profile of the accretion disk.

Progress

Broadly, Dr Middleton leads the observational side of the project and I lead the theoretical side. In Cambridge, I wrote a code to model eclipses in different energy bands. The code takes all General Relativistic effects, including light bending, into account. It assumes that a blackbody spectrum is emitted locally from the disk, with the temperature of the blackbody parameterized by a power law. It also takes into account the energy dependent response of *XMM-Newton* and interstellar absorption.

Figure 1 shows an example of an eclipse calculated from this model. The red, green and blue lines are for 0.5-2 keV, 2-3.5 keV and 3.5-5 keV light curves respectively. It is possible to see energy dependent asymmetry between ingress and egress. Figure 2 makes this clearer. Here, we reverse the egress and shift it in time by an interval which minimizes the difference between ingress and reversed egress. We then subtract this `optimally reversed egress' from the ingress. We see that the asymmetry introduced by Doppler effects creates a characteristic `heartbeat' profile, which depends strongly on the energy band considered.

Remaining aims

During our STSM, I completed the model of an eclipsed accretion disk. We will write this up in a paper detailing the model assumptions and predictions. Dr Middleton determined that the eclipses in EXO 0748-676 do indeed display the energy dependent heartbeat profile demonstrated in Figure 2. He also commenced fitting the model to the data. We will next improve the model to also take into account emission from the NS surface and fit this improved model in a number of energy bands. We will present our results in a paper.

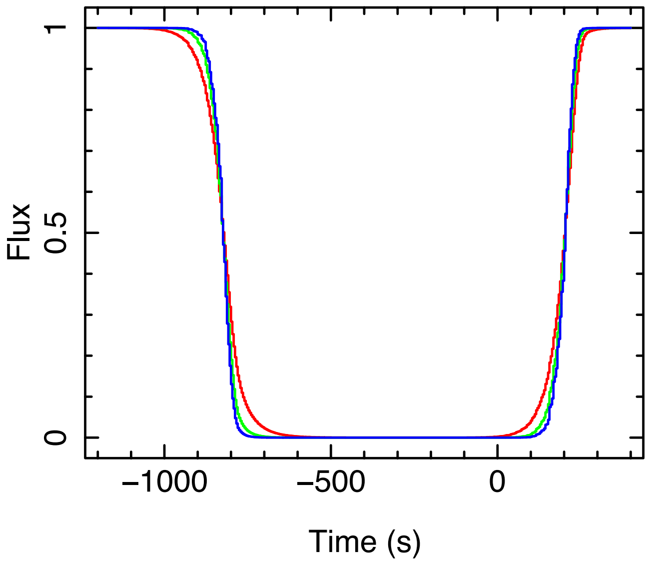

Figure 1: Example of eclipses in three energy bands (see text) calculated using the model.

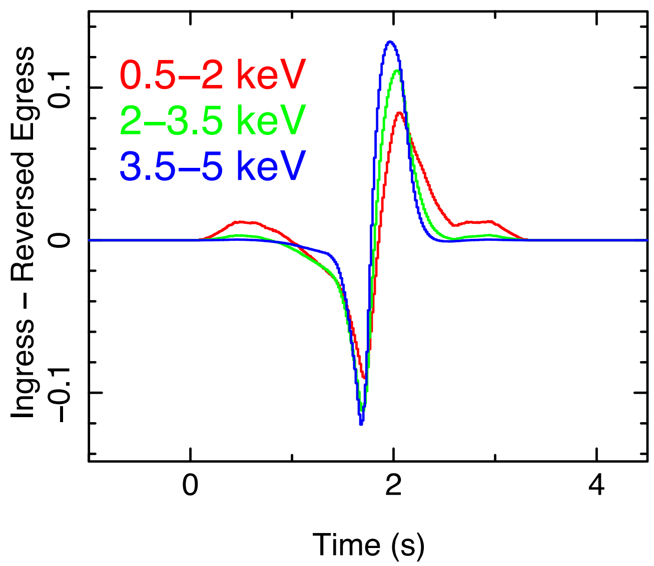

Figure 2: The same eclipse represented as ingress - reversed egress in order to demonstrate the energy dependent asymmetry between ingress and egress.