Abstract

This thesis is comprised of three papers concerning accretion related phenomena around neutron stars and an introduction describing general relativistic radiation magnetohydrodynamics (GRRMHD), numerical techniques for solving the GRRMHD equations on a computer, accretion disks, neutron stars, and some unpublished results.

The motivation for much of the work in this thesis concerns pulsating ultraluminous X-ray sources (PULXs). These are extra-bright ($L < 10^{39}$ erg s^{-1}) extra-galactic X-ray point sources observed outside the centers of galaxies which also show (~ 1 s) coherent pulsations. The pulsations indicate the presence of neutron stars so that the observed luminosities must be many times the Eddington limit ($L_{\rm Edd}$). Much of this thesis is dedicated to understanding the physical processes which could allow accreting neutron stars to produce such large luminosities using numerical simulations and to a small extend analytical calculations.

In Chapter 2, which consists of the publication Abarca and Kluźniak (2016), I extended the results in Wielgus et al. (2015) to include a first order, linear perturbation analysis to study oscillations about the equilibrium configuration of a radiation supported atmosphere. While not directly concerned with PULXs, this paper serves as an illustration of the necessity of including radiation in relativistic hydrodynamics to properly encompass the physics around accreting neutron stars and so it helps to set the stage for the next two chapters. The main result of the publication was that the lowest frequency eigenmode is consistent with the 300-600 Hz quasi periodic oscillations (QPOs) seen in several X-ray bursting low-mas X-ray binaries. However, when the full effects of radiation drag were included in the calculation, the oscillations were found to be over-damped.

The second paper, Abarca et al. (2018) included in Chapter 3, involves simulations of super-Eddington accretion onto a black hole and a non-magnetized neutron star, the later of which obtained a hard-surface implemented as a sticky reflective inner radial boundary condition. The simulations showed that gas collected on the surface of the neutron star and filled the domain with so much material that any radiation released by the accretion disk hitting the surface was trapped. The radiation which was able to escape was found to be nearly isotropic and around one Eddington luminosity which does not resemble a ULX in any sense. This paper made it possible to disentangle the effects of including a magnetic field and a hard-surface into an accreting NS simulation.

The last chapter concerns a letter (Abarca et al. 2021) in which I run a 2D axisymmetric GRRMHD simulation of super-Eddington accretion onto a neutron star with a 2×10^{10} G dipolar magnetic field. In order to handle the large magnetizations present in the magnetosphere I implement the method from Parfrey and Tchekhovskoy (2017) and adapt it to work with GRRMHD simulations. I also use a boundary condition which is meant to model gas hitting the surface, becoming shocked and releasing a fraction (in this case 0.75) of its kinetic energy as outflowing radiation. The disk formed in the simulation is truncated by the magnetic field and the flow is driven along field lines forming accretion columns. A large amount of radiation is released at the base of the column and this radiation becomes collimated by the outflowing gas so that when it reaches the observer it appears to be originating from a source many times brighter ($\sim 140\ L_{\rm Edd}$). The actual amount of released radiation is much smaller, showing that the system is able to beam the radiation to a large degree. This shows that weakly-magnetized accretion neutron stars could be considered to be candidates for PULXs.