**Description for the general public**

The densest known objects in the universe are black holes and neutron stars, the objects left over when a massive star explodes into a supernova. A black hole is an object so compact that anything that falls into it cannot escape, even light. A neutron star is the densest known object, next to a black hole. Deep in their interiors, they are believed to be made of a soup of particles that are only seen on earth in particle accelerators. Near the surface they are made of more familiar ingredients (protons, neutrons, and electrons).

These objects can often be found in pairs with normal stars, orbiting each other in binary systems. Under the right conditions, the normal star can lose some of its gas to the black hole or neutron star. The force of gravity near the surfaces of these objects can be up to a hundred billion times that of Earth's. As the gas falls towards them it forms a disk and spirals inward. As the gas falls inward it is squeezed and compressed causing it to heat up. The gas can get so hot (up to a billion degrees Kelvin), that it begins to emit X-rays. Such systems are called X-ray binaries, and they are just one example of accretion in the universe.

Neutron star accretion is interesting, not only because of the effects of extreme gravity, but also because (unlike black holes) they have hard surfaces and magnetic fields. The interaction of the inspiralling gas with the hard surface and magnetic field of a neutron star can produce even more spectacular emission than gas simply falling into a black hole, never to be seen again.

There are several interesting phenomena involving neutron star accretion that is difficult to explain. One example is called an ultraluminous X-ray source (ULX). It is thought to be an accreting neutron star, but it emits extremely bright X-rays. In order to do this, it must be accreting a very large amount of gas, and at some point, the X-rays can start pushing back on the gas. Another interesting phenomenon is found when measuring the variability of the brightness of an accreting neutron star. Sometimes the brightness can be found to oscillate near a specific frequency, anywhere from a few hundred to a thousand Hertz, in what is known as a quasi-periodic oscillation (QPO). The mechanism that causes QPOs is not well understood. Finally, under the right conditions, the disk of gas described above can be unstable in the inner regions. It can collapse or blow up if its temperature changes even slightly. In this project, we will spend time studying all of these processes.

We aim to study accretion onto neutron stars by running numerical simulations. The simulation works by working out the relevant calculations at discrete points in space, the more points we use, the better the resolution of the simulation, and the closer to reality is the result. Taking into account all of the important physics, General Relativity, magnetohydrodynamics, and radiative processes, requires immense computing power if we want to properly resolve the most interesting parts of the system. Using supercomputers, we can run simulations using hundreds or even thousands of cores (compare this to the typical desktop computer with only around four cores).

So far there have been several simulations of accretion onto neutron stars, but few that combine all the physics mentioned above. We aim to be among the first groups to do so. A simulation like this will help in the understanding of these systems, i.e., why they shine the way they do. Using simulations can check our understanding, we can find out which models explain our observations, and which ones do not. In some instances we can even observe new phenomena, which can be used to build new models. Radiative simulations such as the ones we plan to do, have already proven to be useful for studying accretion onto black holes, and we want to extend that knowledge to neutron stars. We will learn more about the structure of accretion disks around neutron stars, and hopefully more about what causes them to exhibit the strange behavior seen in ULXs or QPOs, among others.