Multi-wavelength observations of neutron stars to constrain their mass and radius

Neutron stars are produced in the supernova explosions of massive stars. These stellar remnants are so compact, with radii of around 12 km and masses of $\sim$1.4 $m_{\odot}$, that they are supported by baryon degeneracy pressure. Their central regions can attain densities of several times the nuclear saturation density, which coupled with the cold nature of the matter, means that we still do not understand what they are composed from. Existing nuclear theories predict many different equations of state, including matter that could be primarily nucleons, but also more exotic species such as hyperons, free quarks, condensates, or strange matter may dominate this regime.

In order to complete our understanding of the nature of matter, we need to understand the cold dense matter inside neutron stars. To do this we rely on astronomical observations to measure the mass, radius and temperature of these compact objects. The mass and the radius give us information on the pressure and density, allowing us to make constraints on the neutron star equation of state. Alternatively, following the temperature of the neutron star with time after being heated due to the accretion of material from a companion star, allows us to constrain the cooling curve, also allowing us to probe the nature of the neutron star interiors.

During this course we will examine different observational methods to constrain the three observational parameters mass, radius and temperature. We will examine constraints that can be made on the mass of the neutron star if it is a member of a binary system, using Kepler's laws. Alternatively, we can study the matter originating from a companion star in the binary system, that forms an accretion disc around the neutron star before losing angular momentum and falling onto the compact object, which can give limits on the size and mass of the neutron star. Observing highly magnetised neutron stars, known as magnetars, we can use X-ray observations to study the thermonuclear bursts that these systems undergo, to give constraints on the mass and the radius. Constraints on these two parameters can also be made by studying the X-ray spectra and lightcurves of thermally emitting neutron stars. We will also take a good look at pulsars and determine how the mass and the radius can be determined by studying their post-Keplerian parameters. We will also examine the cooling nature of neutron stars, giving us insights into the equation of state of the neutron star matter. Finally we will discuss the potential of gravitational waves to uncover the nature of the matter in neutron stars.