

Neutron stars are one of the most exciting, and certainly exotic, nuclear physics laboratories in the universe. These incredibly dense objects are born when a massive star exhausts its nuclear fuel and dies, exploding as a supernova. The core that survives the explosion is no longer supported by nuclear processes and collapses. If the original star was very massive (more than thirty times the mass of our sun) it will continue collapsing all the way to form a black hole, but if it is less massive eventually the interior components will be squeezed together so tightly that they cannot be squeezed any further, and the collapse halts, forming a 'dead' star. For less massive stars the collapse continues until neutrons are pushed together far enough that their quantum mechanical pressure can support the star and one has a Neutron Star. These objects are so extreme that their interior density is higher than the interior density of a nucleus: they have a mass approximately one and half times that of the sun compressed in a 10 km radius, the same as if the mass of the sun were compressed into a space the size of Warsaw. The explosion and collapse of the original star also lead to the formation of a super strong magnetic field, more than a billion times stronger than that of our Sun. Very little is known about how physics works in such extreme conditions, as they cannot be replicated in laboratories on Earth, and the interior of the star cannot be observed with traditional telescopes and detectors. We are, however, at the start of a revolution in astronomy that will forever change our view of the sky and allow us to unlock the secrets hidden in neutron star interiors: the birth of gravitational wave astronomy. Gravitational waves are a prediction of Einstein's theory of General Relativity, which states that violent astrophysical events, involving extreme objects such as black holes and neutron stars, will produce ripples, 'waves' in fabric of space time that could propagate to us and cause the distance between objects to oscillate. The effect on Earth is, however, tiny: a standard gravitational wave would lead to the distance between two objects several kilometres apart changing by less the diameter of a proton. Three large scale gravitational wave detectors have been built, two in the United States, known as Advanced LIGO, and one in Italy, Advanced Virgo. These are interferometers, devices that shoot laser light down two arms several kilometres long, reflecting it on a mirror and measuring how long it takes to come back. If a gravitational wave passes through the instrument it will deform the arms, and lead to a difference in the time the two laser beams take to complete their paths. It is a true marvel of technology and engineering that the instruments are now at the stage in which they can effectively drown out all surrounding noise (thermal oscillations, vibrations due to traffic etc.) and indeed measure variations in arms lengths smaller than a proton to detect a passing gravitational wave. The Advanced LIGO and Virgo team, of which the Polish Polgraw consortium is an important part, made history in 2015, by directly detecting for the first time gravitational waves from two inspiraling black holes, and in 2017 observed the gravitational wave signal from a neutron star binary merger, heralding in a revolution in our understanding of the universe unlike any that has taken place since the first telescope was pointed to the sky. Neutron stars are, in fact, one of the main targets for these detectors. The signals, however, are very weak and theoretical models are needed to help extract the data from the noisy output of the detector, in very much the same way that we can understand what a person is saying in a very noisy background if we can see subtitles.

During such violent events temperatures can reach nearly a billion (10^{12}) degrees and the objective of the project is to model dissipation and heat transport during the merger of two stars and directly after, to determine whether a stable neutron star can be formed.

This project will undertake cutting edge theoretical work to model dissipation and heat transport in Einstein's theory of General Relativity, and perform computer simulations of neutron stars and gravitational wave emission. The results can be compared to new observations of gravitational wave events, that during the current, third observational run of LIGO and Virgo, are becoming commonplace, with new events announced nearly every week. This project will thus contribute materially to the success of huge and revolutionary project that involves more than a thousand scientist in Poland and all over the world, and that will herald a new and exciting age for astronomy and physics.