To find some of the most exciting and exotic nuclear physics laboratories available to scientists we must look to the sky, and in particular to neutron stars. These incredibly dense objects are born when a massive star exhausts its nuclear fuel and dies, exploding as a supernova. Following the explosion, the remnant is no longer supported by nuclear processes and collapses. If the star is not so massive that the collapse cannot be halted, and one has the formation of a black hole (this happens if the original star had a mass roughly more than thirty times that of our sun) 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 'dead' stars 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 sun were squeezed 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, that can deform the star and lead to strong observable energetic phenomena. We are still not sure how Physics works in such extreme conditions, as they cannot be replicated and studied directly in laboratories on Earth. 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. Violent astrophysical events, involving extreme objects such as black holes and neutron stars, according to Einstein's thoery of General Relativity, 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 a part changing by less the diameter of a proton. Nevertheless three large scale gravitational wave detectors have been built, two in the United States, known as Advanced LIGO, and one in Italy, Advanced Virgo, and proved Einstein's prediction to be correct. 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. In 2015 history was made when the Advanced LIGO and Virgo team, of which the Polish Polgraw consortium is an important part, directly detected for the first time gravitational waves from two inspiraling black holes. In 2017 another breaktrhough followed, with the detection of a gravitational wave signal from a neutron star binary merger. Neutron stars are 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. The sensitivity of the instruments has now reached a point where they can hunt for signals from isolated neutron stars deformed by a magnetic field, and combining these results with thoeretical studies and electromagnetic observations will allow us to unlock the secrets of these stars, 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.

The objective of the project is to use state of the art numerical simulations to model the development of the super strong magnetic field in the stellar interior. The task is challenging, as the evolution of the field will excite turbulence in the star, similar to the air turbulence we experience when flying in a plane, and high resolution simulations are needed to capture this behaviour. The results of these studies will then be used to study theoretically the electromagnetic and gravitational wave signals expected from neutron stars, and construct templates to aid observations with telescopes and ground based interferometers.