Imagine crushing all the mass of the Sun into a small sphere with a radius of 10 km (about the size of Warsaw). Of course, we don't have a way to generate the incredible forces needed to do that, but that process is exactly what happens at the centre of a supernova explosion. The result is a strange object called a neutron star. Crushing all of that mass into such a small volume means that neutron star matter is nothing like any material on Earth. The density of neutron stars is impossible to imagine - about a hundred thousand billion times denser than lead. Until the late 1960s these stars only existed in the imagination of theoretical physicists - but then astronomers started to detect regular radio pulses from objects they called 'pulsars' - and physics theory said that these signals could only come from neutron stars. Since then, we have found that many unusual signals from Space come from neutron stars.

One of the most extraordinary properties of neutron stars is that they contain magnetic fields far, far stronger than anything we can generate here on Earth - about ten billion times stronger, in fact. Magnetic fields help to produce the regular radio pulses we see from pulsars, but in some neutron stars the magnetic field powers very violent events: storms of X-ray bursts, abrupt jumps and drops in how fast the star rotates, and huge gamma-ray flares - so bright that they overpower every other signal reaching measuring instruments on Earth at the same time. The magnetic field inside a neutron star is one of the key ingredients needed for understanding how the star behaves - but unfortunately, we don't yet understand what this magnetic field looks like. The problem is that we have no way of looking inside a neutron star - there are no observations which give a clear picture of the internal magnetic field - so we need to understand it by making theoretical models.

Scientists have been making models of neutron-star magnetic fields for years, but because so many pieces of complex physics need to be included, the models have not quite been detailed enough to be realistic so far. This project will change that. The key to making realistic models will be to look at the neutron star's history and how the magnetic field changes over time into the kind of field that sits in a mature neutron star today. We will start by looking at a young neutron star straight after it has been born in a supernova; at that stage it will be a hot, liquid ball. We will model the possible state of the magnetic field for this young neutron star. Then we will simulate the way the neutron star matures and gets cooler, when a number of major changes occur: the outer part of the star will freeze into a solid crust, and the core turns into a superconductor. By doing this we'll be able to understand what the internal magnetic field of a neutron star looks like today, and that in turn will help us understand some of the violent phenomena that these stars produce.