In the vast expanse of the universe, every star meets its inevitable end when its nuclear fuel is exhausted. This captivating phenomenon gives rise to compact stellar objects such as neutron stars, known as the second families of compact stars, in contrast to White Dwarfs as the first family. The primary focus of this research project is to delve into the fascinating properties of these objects. Neutron stars, often referred to as pulsars when emitting periodic light, are born through the explosive gravitational collapse of massive stars, typically weighing more than nine times the mass of our Sun.

Compact stellar objects possess the potential to communicate crucial information through fundamental particles known as neutrinos, which travel at nearly the speed of light. These neutrinos are abundantly produced within the interiors of these objects and hold the intriguing prospect of being observable using the currently operational neutrino observatories on Earth.

To truly appreciate the physics governing these compact stars, we must comprehend their remarkable properties. Neutron stars can weigh up to twice as much as the Sun but have a compact size comparable to a mid-sized city, such as Wroclaw, with a diameter of about 15 km. These stellar objects harbor the most extreme conditions in the entire universe, marked by incredibly high densities that give rise to a quantum phenomenon called degeneracy. As a result, they serve as ideal laboratories to investigate the phases of hot and dense matter within nuclear and particle physics. Neutron stars, in particular, are born with scorching temperatures, making them the hottest entities in the universe since the Big Bang. They have long been regarded as crucial probes for studying the equation of state and potential phase transitions, such as the transition from normal matter to the exotic state known as the quark-gluon plasma. Experimental efforts to recreate this state of matter are underway at the most powerful particle physics accelerators ever constructed. Complementing these efforts, astrophysical simulations of compact stars have played a vital role in providing comprehensive insights into high-density phase transitions through potentially observable signatures, as demonstrated in supernova explosions and binary neutron star mergers.

This proposal introduces a novel scenario where the occurrence of a phase transition can be identified. Roughly one-third to one-half of all massive stars exist within binary systems, and their evolutionary paths often lead to mass transfer from a main-sequence companion star, still undergoing hydrogen fusion, to a compact star that has previously undergone a supernova explosion. This research aims to investigate the outcomes of such mass transfer, including the formation of a neutron star through complete collapse or the ignition of a thermonuclear runaway. Furthermore, it aims to predict observable signatures in the neutrino emission during the accretion-induced collapse of a neutron star, specifically related to the high-density phase transition to quark matter. Neutrinos possess a distinct advantage over light as they are emitted directly from the interiors of compact stars, carrying invaluable information that is otherwise inaccessible.

This proposal represents the cutting edge of high-energy nuclear and particle astrophysics, as the captivating realm of compact stars enters a new era. With the recent detection of gravitational waves from binary neutron star mergers and the presence of current neutrino detectors poised to capture thousands of events from upcoming galactic events, the anticipated research outcomes have broad-ranging implications across various fields. The primary objectives encompass a deeper understanding of the potential outcomes of mass transfer, along with the formation of neutron stars in supernova explosions. Additionally, the project seeks to provide insights into observable signatures within neutrino emissions during the accretion-induced collapse of a neutron star, shedding light on the intriguing high-density phase transition to quark matter.