Abstract for the general public

All stars in the universe end their life when the nuclear fuel is exhausted. As a remnant, a compact stellar object is born. These can be white dwarfs or neutron stars, known as the first and the second family of compact stars in the Universe respectively. They are the key subjects of research of the present project. Neutron stars are also known as pulsars if light is emitted periodically. Their birth is related to one of the most energetic outburst in the modern universe: a gravitational stellar core-collapse supernova. These events are associated with the explosions of massive stars, heavier than about nine times the mass the sun. The remnants of less massive stars are the white dwarfs. Potential messengers from such compact stellar objects are some fundamental particles that travel nearly at the speed of light, known as the neutrinos. They are produced numerously at the interior of compact stars, with the intriguing perspective of becoming already presently observable with the currently operating neutrino observatories at Earth.

The fascinating physics of these compact stars is best viewed in light of their properties: White dwarfs are Earth-size objects that contain about 1.0–1.5 times the mass of the sun, while neutron stars can contain up to about twice the mass of the sun but have a size equivalent to a mid-size city such as Wroclaw, with a diameter of about 25 km. The most extreme conditions anywhere in the Universe are found at their interiors ever since the Big Bang. The very high densities, relatedly, give rise to a quantum phenomenon known as degeneracy. Hence, these compact stars are ideal nuclear- and particle-physics laboratories to study the phases of hot and dense matter. In particular neutron stars are born very hot, featuring the highest temperatures in the Universe ever since the Big Bang too. They have long been considered to probe the equation of state. Especially, a possible phase transition from normal matter to an exotic state, known as the quark-gluon plasma, has long been investigated. At present, this state of matter is aimed experimentally at the most powerful particle physics accelerator facilities ever build. Complementary to that are the effort of astrophysical simulations of compact stars to provide comprehensive insights into such a phase transition at high density through possibly related observable signatures. Recently, this has been successful in the context of supernova explosions and binary neutron star mergers, which resembles a milestone in the field.

In this proposal attention is being brought forward to a novel scenario where the possible occurrence of this phase transition can be identified. About one-third up to one-half of all massive stars are in a binary system. The associated binary evolution is likely to lead to a configuration that transfers mass from the main-sequence companion star, still fusing hydrogen at the interior, to the compact star that had been subject to a supernova explosion previously. Eventually, it will be studied how the neutron star collapses into a meta-stable object due to the presence of the high-density phase transition to the quark-gluon plasma. The remnants of such a highly dynamical processes are expected to be hybrid stars, neutron stars with a core composed of quark matter. Such objects determine the third family of compact stars. About their existence has long been speculated.

The anticipated research outcome of this proposal will be relevant for a broad spectrum of applications and might have consequences for a variety of related fields. Primary targets here are the following two aspects: (1) the yet-incompletely understood possible outcome of mass transfer onto a white dwarf as compact star in a binary system shall be addressed, with the formation of a neutron star in case of a complete collapse or alternatively a supernova explosion of type Ia will take place if a thermonuclear runaway is ignited at the white dwarf interior, and (2) the prediction of observable signatures in the neutrino emission from the high-density phase transition to quark matter during the accretion induced collapse of a neutron star. The advantage of neutrinos is that, unlike light, they are emitted directly from the compact star interiors and hence carry valuable information that is otherwise inaccessible.

This proposal is at the frontier of modern high-energy nuclear and particle astrophysics as the fascinating subject of compact stars research just entered a new era, with the very first observations of gravitational waves from binary neutron star merger and with the present neutrino detectors in place to yield thousands of event from the next Galactic events.