The universe was born in the violent event of the big bang. The state of matter at that moment is yet to be discovered. In fact, little is known about this very early phase of the universe's evolution, except that it featured an extremely rapid expansion. As a consequence, the expanding universe cooled and, at some stage, normal matter formed. However, before atomic nuclei and molecules could exist, a variety of thermonuclear processes took place, involving the lightest nuclear species such as hydrogen, in fact quite similarly to what happens in the sun today. The processes are called collectively big-bang nucleosynthesis. As a result of the big-bang nucleosynthesis, the most abundant and also the lightest elements found in the universe were produced, namely hydrogen and helium. As the universe expands further, these elements were then the building blocks of the first and all following generations of stars. While the big-bang nucleosynthesis is rather well understood, together with the origin of the lightest elements, the origin of the heaviest elements, among them is gold, remains a mystery.

Collisions of two neutron stars—these compact stars are the remnants of stellar explosions of stars more massive than about ten times the mass of our sun, which are known as gravitational stellar core-collapse supernovae—have long been considered as the origin of heavy elements in the universe. And indeed, the very first and so far unique observation, associated with the so-called GW170817 event, which took place on August 17th 2017, it was seen in gravitational waves, optical, gamma- and X-rays, confirmed directly not only the very existence of such neutron star collisions but also that a variety of heavy elements were produced in the aftermath, which is known as *kilonova*. Thereby, the heaviest elements found in the universe were produced, for example lead and even uranium as well as plutonium. With the detection of gravitational waves, not only from this event but also from a number of black-hole collisions, research had entered the new area of multi-messenger astronomy. It was awarded the Physics Noble Prize in 2017.

However, there is a problem when considering exclusively binary neutron star collisions as the source of the heaviest elements found in the universe. Namely, there is an inconsistency with observations of stars that are poorly enriched in iron, or in general collectively known as metal poor, and at the same time rich in the heaviest elements, for example europium and barium are often detected. Note that the main source of iron and all iron-group elements, such as nickel and zinc, are known to be gravitational stellar core-collapse supernovae. These metals are ejected within the associated explosions and thus continuously enrich the interstellar medium with every supernova. The difficulty arises when trying to explain the enrichment of elements heavier than iron in metal deficient stars, because a binary neutron star collision requires time to take place. *First*, two gravitational stellar core-collapse supernovae need to occur, massive stars live several tens up to hundreds of millions of years, and after that *second* the inspiraling of the associated supernova remnant neutron stars. The latter is related to the emission of gravitational waves, which carry away energy and hence the orbital separation decays over the course of millions, perhaps even billions of years. This was first observationally confirmed for the famous Hulse-Tylor pulsar, named after their discoverers R. Hulse and J. Taylor, for which they were awarded the Physics Nobel Prize in 1993. In the end, when binary neutron star collisions happened for the first time during the early galactic evolution, the interstellar medium is already enriched with metals due to several prior supernova explosions. In conclusion, there must be another site operating at low metallicity that produces the heaviest elements. This can only be associated with massive star explosions, the other astrophysical events that had long been considered. Moreover, due to the large scatter of these heavy elements observed at metal deficient stars, it has been concluded that these must be rare events.

In this project two novel sites are brought forward in the context of the chemical evolution of the galaxy. These are associated with massive star explosions that could potentially explain the observed heavy elemental enrichments in metal deficient stars. These are *one* the explosions of white dwarf like objects, that result from the evolution of single stars with initial masses between 8–9 times the mass of the sun as well as from peculiar binary stellar evolution that leaves a so-called ultra-stripped stellar core, and *second* the rare class of massive star explosions that are triggered due to a phase transition from normal nuclear matter to the exotic state of high density matter known as the quark-gluon plasma. This relates to the puzzle of the yet-incompletely known state of matter at extreme conditions, presumably present during the very early evolution of the universe. Since such conditions cannot be probed in experiments, not even in the most powerful particle accelerator facilities ever built, large-scale computer simulations of explosive astrophysical processes are ideal laboratories to probe the possible existence of such exotic phases of matter. Therefore, the Institute of Theoretical Physics at the University of Wroclaw is the European node for studies of matter under extreme conditions in astrophysics.

If successful, the inclusion of these two novel sites into state-of-the-art computer models that simulate the galactic chemical evolution will provide the answers to the current riddles associated with the presence of heavy elemental enrichment and their large scatter observed in stars that are iron poor.