Production of black holes and gravitational waves from cosmic phase transitions

Space research that we, as a humankind, have conducted during the last hundred years has significantly enhanced our knowledge of the Universe, its evolution, and its future. The development of our scientific understanding of the Universe has been especially impacted by the discovery and ongoing investigation of the *cosmic microwave background*. According to our best knowledge, this has provided a very precise description of the state of the Universe around 400,000 years after the *Big Bang* and allowed us to make predictions regarding its further evolution. Nevertheless, even though our discoveries made it possible to answer a vast number of questions about the history of the Universe, they revealed a multitude of other problems and uncertainties that we haven't managed to solve yet.

Among these unsolved mysteries, one of the most important is the problem of Dark Matter. The results of numerous experiments, such as measurements of galaxy rotation curves, gravitational lensing, and the cosmic microwave background, suggest the presence of matter of unknown nature, which is known as the *Dark Matter*. Dark Matter interacts very weakly with the common, baryonic, matter, which significantly impedes its direct detection and study in terrestrial laboratories. Thus, simultaneous indirect searches for Dark Matter are being carried out, aimed to characterize Dark Matter by investigating its impact on particular phenomena in the cosmic space.

Despite difficulties in getting positive results form experimental research, scientists persistently work on improvements of theoretical descriptions of Dark Matter. One promising possibility to explain the Dark Matter problem is a hypothesis that a part, or even the entirety, of Dark Matter is in the form of black holes. For this to be possible, the majority of black holes would have to emerge from processes other than gravitational collapse of massive stars. Primordial black holes can be a potential answer, as they are apt to form due to many mechanism that may have occurred at the very early stage of the Universe's evolution.

A necessary condition allowing for the formation of primordial black holes is the presence of regions with increased energy density, which collapse into an extremely small volume due to gravitational interactions, forming a black hole. Such regions could have possibly originated due to energy density fluctuations sourced by first order cosmic phase transition. Such transitions proceed through the nucleation of true vacuum bubbles in a Universe filled with false vacuum, in a manner resembling the boiling of superheated liquid. Domains in which bubble nucleation occurs slightly later than in their surroundings are characterized by higher relative energy density, which, upon exceeding critical value, enables gravitational collapse and formation of black hole.

Previous research on the topic of black hole formation during phase transitions suggests that transitions allowing for the production of a significant abundance of black holes are also characterized by the emission of a strong gravitational wave spectrum. Depending on the properties of the phase transition, this may account for the stochastic gravitational wave background observed by running experiments (Pulsar Timing Arrays), or might be detectable in experiments planned for the near future (e.g. Laser Interferometer Space Antenna). Proper measurement, analysis, and theoretical description of gravitational wave signals may provide groundbreaking results, specifically because gravitational waves may carry information about processes that occurred before the emission of the cosmic microwave background. This could provide direct insight into phenomena that happened so early after the Big Bang that we are unable to probe them by any other means.