General Public Summary: "Astrophysics of gravitational waves" (PI: K.Belczynski)

One of the most important predictions of Einstein *General Relativity Theory* were gravitational waves. Since this prediction, in 1915, scientists were trying to prove (or disprove) the existence of gravitational waves. The first indication that they exist came in 1974. Russell Hulse and Joseph Tylor discovered a double pulsar system: a binary consisting of two neutron stars. The two orbiting neutron stars, according to the Einstein's theory should emit gravitational waves and therefore should be getting closer and closer to each other. In fact, such approach was measured confirming the existence of gravitational waves (alas indirectly), and both scientist were awarded Nobel prize in 1994.

Following this indirect confirmation, scientists have begun a long quest to detect the gravitational waves directly. Gravitational waves distort spacetime; for example changing distance between two free-floating masses. The stronger the wave the larger the displacement. However, spacetime is very stiff medium and the expected displacements are extremely small. So only the most violent and catastrophic events may possibly generate waves strong enough to be measurable. Astronomers have identified such catastrophic events looking through the depths of Universe. For example, two orbiting neutron stars do not emit waves strong enough to be directly detectable. However, if such two neutron stars are to be accelerated to the speeds that are a significant fraction of the speed of light and if they collided then such a crash is potentially detectable...

The construction of gigantic USA *Laser Interferometric Gravitational-wave Observatory* (LIGO) begun in 1990-ies. At the cost of about 300 million dollars the new observatory was ready and begun taking data looking for gravitational waves around 2000. Observations lasted for 10 years, and despite big hopes nothing was detected. In the following years; 2010–2015, the LIGO undergoes a big upgrade and its reach into Universe is significantly extended. In 2015 it is turned on again. Within first few days of observations, the strong gravitational wave is passing through two LIGO detectors. To surprise of many, not only it is not a signal expected from collision of two neutron stars, but from collisions of two black holes, but also these are not your *ordinary* black holes.... These are monstrous heavy black holes that were never observed before! The new discipline of science is just born: gravitational wave astronomy.

Black hole collisions were considered as potential sources of gravitational waves since early 1990-ies. However, only starting from 2010 our studies revealed that black holes can form with much larger mass than typically assumed and that the collision rates are much higher outside of Milky Way that was so far used for the early estimates. With our new model, we have predicted that black hole collisions should not only be the first source detected by LIGO (and Virgo; European gravitational wave observatory), but also that they should significantly dominate over neutron star collisions. So far LIGO/Virgo has detected 6 collisions of black holes and only one crash of neutron stars.

With our verified model we are participating in the development of this new discipline of gravitational wave astronomy. With this new window on Universe just opened there is great expectation that new quality science will emerge. Our proposal is aimed at taking full advantage of the existing LIGO/Virgo observations. We will also use forthcoming detections to build physical model of evolution of stars that form neutron stars and black holes. Formation of compact objects, involves a number of long-standing problems in stellar astrophysics. Do all massive stars die in supernovae explosions? How do stars survive violent interactions in binary systems? What is the maximum mass of stellar-origin black holes? What is the role of neutron star mergers in enriching Universe in top heavy elements? What does a detection of neutron star merger imply for astrophysics? What are the most likely evolutionary channels and galaxies that produce gravitational wave sources? We will be addressing all these issues in the forthcoming 5 years sponsored by Polish National Science Foundation (NCN).

Our computer model allows to create a synthetic Universe filled with stars and follow their evolution since Big Bang till present. Across the eons of time neutron stars and black holes are born and are tracked till they are detected by our artificial LIGO/Virgo observatory. The results depend sensitively on our assumed physics that sets birth, evolution and death of stars. Modifications of the physics (modeling) will be guided by LIGO/Virgo observations (comparisons of our computer predictions with real world) to get insights into inner workings of massive stars. Our heavy computations (billions of stars) will be performed both on supercomputers and with the use of personal computers of a world-wide network of volunteers (through citizen science based program: `Universe@home`).