

Science with Gravitational Waves in the Era of LIGO-Virgo-KAGRA Discoveries

Gravitational wave astronomy started with the detection of the merger of two black holes in 2015. Since that time we have seen its exponential growth. Currently we know about 100 sources. Gravitational wave observations have allowed us to make a number of breakthrough discoveries. It has shown that there are black holes with masses far above those measured in X-ray binaries. General relativity was proven to be right in the strong field regime that was inaccessible until recently. The detection of binary neutron star merger GW170817 that was accompanied by a gamma-ray burst opened the new field of multi-messenger astronomy. This event alone also provided several breakthrough discoveries apart from solving the nearly half century old problem of the origin of gamma-ray bursts. It allowed us to measure the speed of gravity, to solve the problem of formation of heavy elements in the Universe, to measure the expansion of the Universe independently of the cosmic distance ladder, just to name a few. Currently we are entering the next stage in the development of gravitational wave astronomy: the observational run O4 has just started.

Polish scientists took part in these discoveries as a part of the POLGRAW group, a member of the Virgo Collaboration. In this proposal we present a broad set of actions to be taken by Polish scientists from six institutes with the aim to maximally exploit scientific opportunities provided by gravitational wave observations and to contribute to improving sensitivity of the Virgo detector.

We will organize the work in three work packages. The first work package is devoted to improving the sensitivity of the Virgo detector by understanding and mitigating two types of noise: the gravity gradient and the magnetic noise. The second work package will concentrate on data analysis and development of tools and algorithms for data analysis. In particular we will work on the search for course of continuous waves, such as all sky search, targeted search with the particular goal of finding r-modes from a pulsar in Large Magellanic Cloud, modern data analysis tools to search for relevant information in a large stream of text messages on electromagnetic transients. Additionally, we will work on searches for burst-like signals originating from nearby supernovae with the aim of understanding these cosmic explosions and the process of formation of compact objects. The third work package will concentrate on astrophysical aspects of gravitational wave astronomy. We will work on the structure of compact objects and investigate how the astronomical constraints help the gravitational wave analysis but also what the gravitational wave constraints imply about compact objects. We will also investigate the properties of the population of merging compact objects and on their formation scenarios. This will involve analysis of the statistical properties of the population but also detailed investigation of individual mergers with well constrained parameters.

We will increase the already substantial Polish contribution to the progress of the interdisciplinary and international field of gravitational wave astrophysics, and foster growth in this field in Poland. In particular, the institutes involved in this proposal are recognized as leaders in gravitational wave data analysis, studies of neutron star interiors, interpretation and modeling of gravitational wave detections, and gravitational wave detector instrumentation. In order to stay competitive in this rapidly developing research domain, this project will further establish Poland as a center of excellence for gravitational wave astrophysics, and help to attract world-class students and researchers to Poland.