Echoes from the dark universe: primordial gravitational wave spectra from cosmological phase transitions

Marek Lewicki

About 13.8 billion years ago, the Universe as we know it came to be in a phenomenon called the *Big Bang*. Most of the data we have on this early period in the history of the Universe comes from cosmic microwave background (CMB). It was produced around 379000 years after the Big Bang, as the temperature of the expanding Universe dropped enough to stop electrons scattering due to constant collisions with other particles. This led to the formation of unionised atoms which are electrically neutral and from this point on the photons previously scattered by charged plasma could propagate freely. The radiation from that time arrives to us to this day from all sides painting an ancient map of the sky as it was in the early Universe. New experiments are continuously devised to read that map in greater detail and infer more information on the evolution of the Universe upon its creation.

Despite this knowledge, the era before the creation of the microwave background remains a mystery to science even though it is crucial for our understanding of the Universe. At this stage, the processes behind our unexplained observations had taken place. Starting with the creation of the so-called baryon asymmetry thanks to which all of the objects we observe, formed from matter, do not annihilate upon interacting with antimatter which seems to be simply absent in our Universe. Another problem is the origin of dark matter which plays a key role in the creation of structures such as galaxies.

In view of these problems of modern physics, it is natural to look for other carriers of information that could allow us to study the earlier history of the Universe. Fortunately, in 2015 we were able to observe such a new carrier for the first time. These are gravitational waves, i.e. microscopic disturbances in space-time. We are able to detect them thanks to huge laser interferometers of extraordinary precision. Current experiments of this type have detected relatively recent very high-energy events, mainly collisions of black holes with masses tens of times larger than the mass of the sun. The planned next-generation experiments, such as the Laser Interferometer Space Antenna (LISA) and the Einstein Telescope, thanks to their greater sensitivity, give hope for the detection also of gravitational waves originating in the early universe.

In 2023 first observation of a background of gravitational wave background at very low frequencies more akin to the CMB map was confirmed. The discovery was made thanks to the impact these very long gravitational waves have on the motion of millisecond pulsars. The origin of this background is still unclear and multiple interpretations including one originating in the early Universe are still possible.

One of the possible sources that could produce gravitational waves in the early universe is a first-order phase transition. Such transitions are violent events similar to what transpires in boiling water as the bubbles of the new phase nucleate in the volume filled by the initial phase. Many extensions of the Standard Model aimed at solving the puzzles of modern cosmology feature such events. The aim of this project is to accurately compute the features of the stochastic GW background such a transition would produce allowing its identification. This will open a new possibility for catching a glimpse of events taking place within seconds after the Big Bang.