We exist, so there must also be some sort of asymmetry between matter and antimatter. Otherwise, the whole matter and antimatter would long ago have turned into photons, i.e. light, as a result of mutual annihilation of particles and antiparticles. The explanation of this asymmetry, essentially identical with the explanation of the existence of matter in general, is one of the most interesting cognitive challenges of modern physics and cosmology. Therefore, the physical processes that took place in the early stages of the universe's evolution are so interesting for researchers and contributed to a number of hypotheses. Unfortunately, none of them is able to give a complete explanation of the violation of symmetry between matter and antimatter without reference to entities or phenomena that are experimentally unconfirmed. Currently we observe more than a thousand million times more light than matter in the universe. The remnant that survived the great annihilation is made of the quarks and leptons. Quarks are the building blocks of atomic nuclei, and leptons are such particles as electrons. Sakharov gave the necessary conditions that must be met for some matter to survive an early stage of evolution of the universe. These include breaking the charge symmetry (C), which is a violation of the invariance of the physical processes due to the exchange between particles and antiparticles, and breaking the charge-spatial symmetry (CP), which involves converting particles into anti-particles, connected with a mirror reflection in space (P). So far, violation of charge symmetry C and charge-spatial symmetry CP was only observed in the processes induced by the weak force. In contrast, despite many experimental trials in a number of leading laboratories all over the world, we have never observed any asymmetry between the behavior of matter and anti-matter in the processes induced by gravitational, electromagnetic and strong forces, which are interactions that determine the existence of stars, atoms and atomic nuclei. In addition, violating the CP symmetry has been confirmed empirically only in two (K meson and B meson) of the hundreds of known particles made of a quark and an anti-quark, although a violation of this symmetry is yet to be observed in the processes involving leptons.

The aim of this project is to search for cases of breaking the discrete symmetry in the decay of positronium atoms to photons. Positronium atoms, which consist of an electron bound with an anti-electron, are a system made of only leptons and, being made of matter and anti-matter, are ideally suited to testing invariance with respect to the conversion of particles into anti-particles. The proposed project raises the current issues for research in physics and cosmology. This is confirmed by the fact that a similar scientific purpose, namely the observation of breaking of discrete symmetries in systems made only of leptons, is part of long-range research plans in flagship neutrino-related experiments in Japan and the US, where researchers are seeking to observe CP symmetry violation of symmetry in the oscillations of neutrinos and antineutrinos send, e.g. from the J-PARC laboratory to the distant Super-Kamiokande detector about 295 km away, or from Fermilab to the Nova detector, 810 km away. It should be noted, however, that the fundamental purpose of this project is similar, while using a different methodology - if discrete symmetries in lepton systems are violated, it gives a great chance to discover them.

The experimental aim of the project is to perform (for the first time in a Polish laboratory) a study of the invariance of physical processes due to the conversion of electrons into anti-electrons, with an accuracy exceeding more than a hundred times the previous such experiments carried out in the leading research centers in Japan and USA. The research will be carried out using the Jagiellonian Positron Emission Tomography (J-PET), built in 2015 at the Jagiellonian University based on a new technology for noninvasive imaging of the inside of human body, developed by the Head of the grant. The innovative nature of this method is confirmed by 16 international patent applications. The project is a unique example of how the technology that can be used for the purposes of medical imaging opens up the possibility of performing basic research on the most fundamental questions about our existence that can help us understand the evolution of the universe.

Positronium atoms (e+e-), which are also anti-atoms, will be produced inside the diagnostic chamber, by irradiating aerogel phantoms with anti-electrons emitted from a radioactive sodium source. The photons emitted during the annihilation of positronium atoms will be recorded by the tomograph, which has as significantly improved spatial and temporal resolution compared to the units used in the preceding experiments; moreover, with the newly developed technique of detection, the J-PET will allow reaching a hundred times greater sensitivity in examining the degree of symmetry breaking in purely leptonic systems. In addition, J-PET tomography provides the unique ability to measure the polarization of photons, giving ground for testing discrete symmetry in nature in ways that have been impossible in earlier experiments!