Developing new methods of analysis of data from the Pierre Auger Observatory

The proposed project aims to improve methods used in the experimental study of cosmic rays at energies above 10^{18} eV. Particles with such high energies - several orders of magnitude higher than the energies obtained in man-made particle accelerators - arrive on Earth from deep space. With today's technology, an accelerator like the Large Hadron Collider would have to be the size of Mercury's orbit to achieve these energies. We do not know where in the Universe the sources of these particles are located or how they are accelerated to the observed extreme energies. However, there is no doubt that particles with such gigantic energies really do reach us from the Cosmos; their origin and their acceleration mechanism are one of the greatest mysteries of modern astrophysics.

The flux of cosmic rays of the ultra-high energies is extremely small: less than one particle per century falls on an area of one square kilometer. It is therefore necessary to build a huge detector to observe them. Moreover, cosmic rays of extremely high energies are observed only indirectly, by observing so-called extensive air showers initiated by primary particles. What can be observed are cascades of secondary particles moving through the atmosphere and eventually reaching the ground. A giant cosmic ray detector array was constructed to experimentally study such showers: the Pierre Auger Observatory, located near the town of Malargue, in the province of Mendoza, Argentina. It is a hybrid detector that combines different techniques for observing air showers. The surface detector stations are spaced 1.5 km apart. The observatory consists of a network of 1660 particle detectors, spread over an area of about 3000 km^2. The second detection system uses a faint glow (fluorescence) caused by collisions between air shower particles and air molecules. On dark, moonless nights, finely tuned telescopes can measure this faint light. The total amount of light depends on the number of particles in the air shower, which in turn depends on the energy of the primary cosmic ray particle initiating the shower in the atmosphere. The system consists of 4 fluorescence detector stations observing the sky above the network of surface detectors.

The results obtained so far at the Pierre Auger Observatory have dramatically expanded our understanding of cosmic rays of ultra-high energies, but some of these results are very surprising and their interpretation is still unclear, such as the observed suppression of the cosmic ray flux above energies around 4×10^{19} eV. Such a feature has been predicted to be a result of the interaction of cosmic rays with the cosmic microwave background (which is a remnant of the Big Bang) and is known as the Greisen-Zatsepin-Kuzmin (GZK) cutoff. However, experimental data on the composition of cosmic rays collected by the Pierre Auger Observatory suggest that the suppression of the spectrum may not be caused by the GZK effect alone, but may also be interpreted as the result of the particle acceleration limit of the sources. These studies show that cosmic rays at extremely high energies are not just protons and/or iron nuclei, but that there may be a significant component of nuclei with intermediate masses in the observed cosmic rays. The key to solving this problem is to determine the composition of ultra-high energy cosmic rays (preferably for individual events).

The most reliable cosmic ray composition studies are currently possible with fluorescence detector observations, which can only operate on dark, moonless nights and under good weather conditions. This limitation of the observation time translates into lower statistics of the collected data, allowing accurate studies of the mass composition only up to energies of 4×10^{19} eV, i.e., just below the suppression region of the cosmic ray particle flux. At the same time, data from the surface detector reach above 10^{20} eV. However, the precise determination of cosmic ray composition based solely on the surface detector has been very difficult so far due to large systematic uncertainties. Therefore, the Pierre Auger Collaboration decided to upgrade the capabilities of the surface detector system. This upgrade will allow more accurate measurements of the nature of air shower particles at ground level, in particular to separate signals from the muonic and electromagnetic components of extensive air showers.

As part of this project, we will participate in the work of the entire Pierre Auger Collaboration to validate the upgraded devices, as well as to prepare the tools that will be used to analyze the new data. We plan to use both proven statistical methods (e.g., principal component analysis) as well as new promising tools provided by the recent development of techniques based on neural networks. The results of the proposed project will contribute to progress in the study of the composition of cosmic rays of ultra-high energies, which will bring us closer to a definitive explanation of their nature and origin.