Non-thermal electron beams as a tool for studying energy transport procesess in solar flares

Solar flares are one of the most energetic phenomena in the Solar System and one of the most effective particle accelerators. The source of the flares is magnetic reconnection, i.e. switching of the lines of force of the magnetic field, during which magnetic energy is released. A significant amount of energy is emitted in the X-ray range. This process takes place in the solar corona, where particles are accelerated. Particles move towards open field lines into interplanetary space or move along closed magnetic field lines towards denser layers of plasma. The commonly accepted solar scenario suggests magnetic field loops anchored in the chromosphere. When they reach the chromosphere, which is much denser than the solar corona, they collide with the atoms of the medium and lose their energy. This causes an increase in pressure in the dense chromospheric plasma, which is heated to temperatures of 10^7 K. Then the chromospheric evaporation process occurs - the plasma begins to fill the magnetic structures, which is observed in the X-ray range as solar flares. Beams of high-energy particles, mainly electrons, moving in the solar atmosphere, make it possible to study the dynamics and physical properties of flare plasma, e.g. plasma density distribution in flare loops.

The interplanetary mission Solar Orbiter (SolO), part of the ESA COSMIC VISION 2015 - 2025 program, was created to answer questions about the heating of the solar corona, the formation of the solar wind, its impact on our planet (the impact of high-energy particles) and the 11-year cycle of solar activity. It is the most complex mission in the history of heliophysical observations. The mission that has come closest to the Sun so far is the Parker Solar Probe (last perihelion on September 27, 2023: $\sim$7.3 million km), but SolO is the only mission that can take close-up images of our star (perihelion 42 million km, i.e. $\sim$0.28 AU). In addition, the mission is to observe the poles of the Sun, which to this day remain an unknown area. The launch of the mission took place in February 2020, and in June of the same year the first images of the Sun were taken. Ten instruments have been placed on board the SolO, including Spectrometer Telescope for Imaging X-rays (STIX) for imaging in the energy range of 4 - 150 keV. The angular resolution of the instrument is 7 arcsec, but remember that SolO will approach the Sun to a distance of $\sim$0.28 AU. At a perihelion of 1 arcsec it will be $\sim$202 km. Then the spatial resolution of the instrument will reach unprecedented in this range of radiation $\sim$1500 km.

The main task of this project is to analyze the effects of non-thermal electron beams hitting the chromosphere during solar flares. Electrons are the main carrier of energy in a solar flare, and energy deposit locations are critical to the energy balance and modeling of these phenomena. In this project, the observations of X-rays recorded by STIX (spectra and images) will be compared with the modeling of the processes of non-thermal electron beams hitting the plasma. Imaging will be performed using the MARLIN algorithm developed by a team from the Space Research Center of the Polish Academy of Sciences. To modeling the process we are going to use the Monte Carlo methods. Currently, the Sun is in the maximum phase of the 25th activity cycle. Taking into account also the distance at which SolO will approach our star and the possibility of detecting active phenomena that are too weak to be observed from a distance of 1 AU, we will be able to collect enough solar flares in the next three years to carry out the planned research. Due to the limited time of the mission, this is probably the only chance to carry out of the project.

The Space Research Center of the Polish Academy of Sciences is one of the key members of the SolO mission, which contributes to the construction of the STIX instrument and creates the software for analyzing data recorded by this instrument. The experience gained during the implementation of the grant will contribute to a better understanding of the processes occurring in the initial phase of solar flares.