Interstellar medium in the vicinity of the Sun: inferences from analysis of the flux of neutral atoms

The interstellar space in the Galaxy is filled with a magnetized plasma called the interstellar medium. Interstellar medium includes regions with significantly different physical conditions, like temperature, density, and ionization degree. The Sun is inside the Local Interstellar Cloud (LIC), which has a total density of ions and neutral atoms equal to ~0.5 cm^{-3} and a temperature of 7500 K. LIC is one of many interstellar clouds with similar parameters, moving relative to each other at a few km/s, embedded in the so-called Local Bubble, which is a region of a very low density (~0.001 cm^{-3}) and high temperature (~10^6 K). This astrophysical object was created due to a series of supernova explosions a million years ago. The Sun emits the solar wind, which carves a cavity in the LISM, called the heliosphere. Heliosphere shields the Solar System against direct influence of the ambient interstellar plasma. The Sun is moving relative to the surrounding interstellar medium, and as a result, the heliosphere has an elongated, comet-like shape. A few years ago, after 35 years of travel, Voyager 1 crossed the boundary between the heliosphere and the outside interstellar environment, called the heliopause, which happened at 120 AU from the Sun (i.e., at a distance 120-fold larger than the Sun-Earth distance). Beyond the heliopause, it is now sampling of the interstellar environment. However, during the long travel, some of the Voyager's instruments failed, including the plasma instrument. Therefore it is important to have alternative ways of studying the interstellar medium just in front of the heliosphere. The action of magnetic fields inside and outside the heliosphere prevents interstellar charged particles, like ions and electrons, from penetrating inside the heliosphere and therefore they cannot be observed near Earth. But neutral atoms do not have these limitations. Therefore they are an interesting target for observations from the Earth's orbit, since they bring information on the interstellar matter. Inside the heliosphere, they follow trajectories slightly bent by the solar gravity and radiation pressure, and the direction from which they arrive can be easily identified.

IBEX is an Earth satellite dedicated to measurements of ENA flux within an energy range 0.01 – 6 keV (for a H atom, 1 keV corresponds to ~440 km/s). The proposing group from SRC PAS has participated in the IBEX project since the mission definition phase. Among others, based on measurements of interstellar neutral helium, we determined its temperature at ~7500 K and the inflow velocity at ~26 km/s. We have also discovered a new population of neutral helium, which we dubbed the Warm Breeze, flowing from the portside bow of the heliosphere. It seems its source are interstellar ions, heated and compressed in front of the heliopause due to the ramming of the heliosphere against the interstellar matter. These ions are neutralized due to charge exchange with ambient neutral atoms. According to heliospheric models, the deflection of the Warm Breeze from the main inflow direction is in the plane defined by the local magnetic field vector and the velocity vector of the interstellar matter flow.

At higher energies, IBEX observes energetic neutral atoms (ENA) of hydrogen. These atoms are created due to charge exchange between a high energy ion and an interstellar H atom. One of unexpected discoveries made by IBEX was the Ribbon, which is a large arc-like region of enhanced ENA emission in the sky. Among many models proposed to explain the Ribbon, the most likely seems the so-called secondary ENA model: the atoms making up the Ribbon are created just beyond the heliopause from high energy ions in the locations where the magnetic field lines are almost perpendicular to the IBEX lines of sight. The original seed for these ENAs are solar wind ions, neutralized by charge exchange inside the heliosphere. This model explains many of Ribbon features, but not the change of the direction of the Ribbon center with energy: the model predicts only a slight shift contained in the Warm Breeze deflection plane, while in reality the shift is larger and almost perpendicular to this plane. INCA onboard the Cassini Saturn probe is another instrument observing ENAs, but with energies larger than IBEX. INCA discovered another arc-like region of enhanced ENA emission: the INCA Belt, which is similar to the Ribbon, but displaced by ~35°.

Within the project, we plan to investigate if the Ribbon and the Belt are due to the same physical phenomenon, or if their origins are different. In one of the hypotheses we plan to find out if it is the structure of the solar wind (slow in an equatorial band, fast at the poles) that is responsible for the apparent shift of the Ribbon on the sky with increasing energies. In another hypothesis, we will investigate if an interaction between the LIC and the neighboring interstellar cloud, or the LIC and the hot plasma within the Local Bubble may partly explain observations in the higher-energy ENAs, and if this may explain the Belt. It also might facilitate determining the distance to the LIC boundary, which cannot be directly assessed from the classical telescopic observations and is indirectly predicted somewhere within 20 000 AU. Explaining the observations as due to processes operating within this boundary region could facilitate better understanding this region and more generally the processes operating at the boundaries of interstellar clouds and in the interstellar medium.