Interaction of the local interstellar medium with the heliosphere viewed by a new NASA space mission IMAP

The Sun is moving through magnetized, partly ionized, dusty interstellar matter. This matter is a portion of a complex of interstellar clouds within a region known as the Local Interstellar Medium, which is a remnant of a series of supernova explosions a few million years ago. The Sun emits the solar wind – an ever-evolving, omnidirectional, latitudinally structured, hypersonic outflow of a hot, magnetized solar coronal plasma. Subjected to the ram and magnetic pressure of interstellar matter, the solar wind slows down through a shock wave called the solar wind termination shock and forms the inner heliosheath. Eventually, it flows downstream past the termination shock, forming the heliotail. The interstellar plasma is separated from the inner heliosheath by a discontinuity surface called the heliopause, which is transparent for neutral atoms. In front of the heliopause, a region of interstellar matter is disturbed by the heliosphere, just like a bow wave in front of a sailing ship: the outer heliosheath. In this region, the neutral and ionized populations are no longer in equilibrium and interact with each other, producing new, so-called secondary populations of atoms and ions. The interstellar magnetic field reacts to this perturbation, appropriately draping on the heliopause.

Interstellar neutral (ISN) atoms, mostly H and He, as well as O and Ne, penetrate the heliopause and form the so-called ISN wind. Some of these atoms exchange electrons with ions from the solar wind. As a result, a former solar wind ion becomes an Energetic Neutral Atom (ENA) and runs away freely from the reaction site, while the former neutral atom, now ion, is picked up by the flowing plasma and joins a suprathermal ion population embedded in the shocked solar wind, suitable for further charge exchange with the neutral wind. The ENAs created in the charge exchange reaction are like photons in astronomy: they carry information on the remote regions of the heliosphere, where they originate. Some of them are re-ionized underway, which attenuates the ENA flux measured inside the heliosphere closer to the Sun.

The flux of ISN is measured by a presently operating NASA space mission Interstellar Boundary Explorer (IBEX). Owing to these measurements, important features of the local interstellar matter and its magnetic field have been determined. But coherent, clear picture is still missing, and the magnitudes of the measured parameters are correlated with each other and thus uncertain. Furthermore, a recently obtained evidence suggests that the portion of interstellar matter currently penetrated by the Sun is in a mixing state or that some unknown processes operate that result in a lack of equilibrium. Moreover, based on analysis of IBEX measurements, we suspect that the present absolute calibration of the solar EUV radiation might biased, up to 40%. If this was the case, this would strongly affect not only interpretation of heliospheric measurements, but also the physics of the atmosphere of the Earth, planets, and planetary moons.

A new opportunity to extend our understanding of the interaction between the Sun and its Galactic neighborhood appears in 2025 with the launch of a new NASA space observatory Interstellar Mapping and Accelerating Probe (IMAP). With IMAP, there will be no current limitations on the viewing geometry that IBEX has had. IBEX can only look perpendicularly to its Sun-centered rotation axis, which results in a correlation between the flow parameters of ISN gas retrieved from the data. IMAP will be able to adjust this angle, which results in extending the observation time of ISN gas during the year, which provides a new, wider perspective.

Recently, we suggested methods of harnessing IMAP observations to remove the correlation between the ISN flow parameters and determine the ionization rate of interstellar helium, which is almost solely due to the solar EUV radiation. We also pointed out science opportunities resulting from the enhanced observation capability of IMAP and suggested an observation scheme to address these opportunities during a two-year nominal mission of IMAP. Within the project, we plan to carry out the plan. To that end, we will also use IBEX data. We will reduce the uncertainty of the flow parameters of ISN He, Ne, and O and search for differences, telltale of nonequilibrium in the interstellar matter. We will look for the secondary population of ISN O and investigate those of ISN He and H to get a better insight into processes in front of the heliopause. We will determine the ionization rate of He and verify the absolute calibration of the solar EUV output. We will lead some of the topics and support other members of the IMAP science team in the others. We will continue to support the IBEX and IMAP science teams in interpretation of heliospheric ENA measurements, in particular in the assessment of the attenuation of the ENA flux inside the heliosphere due to re-ionization.