Modulation of Selected Species of Neutral Interstellar Gas and Their Derivative Populations in the Heliosphere Due to Solar Activity Cycle Effects

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Abstract

The subject of this PhD dissertation is the modulation of the interstellar neutral gas (ISN) and its derivative populations, like energetic neutral atoms (ENAs) and pick-up ions (PUIs), inside the heliosphere due to the solar activity cycle effects. The Sun emits into the space a supersonic flow of particles and a flux of extreme ultraviolet (EUV) radiation that both create the environment in the Solar System and in the Local Interstellar Cloud in which the Sun is embedded. As a result of interaction of the solar plasma with the interstellar plasma a cavity around the Sun, called the heliosphere, is created. The neutral component of the local interstellar medium (LISM) can enter freely the heliosphere and can be detected in the vicinity of the Sun, bringing information about the physical processes at the edges of the heliosphere. The ISN gas interacts with the solar wind particles and solar EUV radiation inside the heliosphere being finally ionized and thus creates new populations of heliospheric particles, like PUIs that are picked-up by the ambient magnetic field. Also ENAs that are created at the edges of the heliosphere and which enter the heliosphere are ionized by the solar factors. The ionization can be due to the charge exchange, photoionization, or electron impact ionization reactions. The solar wind and the solar EUV radiation varies in time with the cycle of solar activity. In this thesis we studied the modulation of the solar ionization factors in time and in heliolatitude and the effect of this modulation on the observations of the ISN gas, ENAs, and interstellar PUIs observed from the Earth's orbit. We developed a model to reconstruct the variation in time of the heliolatitudinal structure of the solar wind proton speed and density based on the available and carefully selected measurements in and out of the ecliptic plane. We constructed a composite photoionization rate model based on available measurements of the EUV flux and carefully selected series of the EUV proxies. We used these models to calculate the ionization rates for the H, He, Ne, and O species and to assess of their survival probabilities in the heliosphere. The models were next employed to study the density of the interstellar species as expected at the Earth's orbit, to determine the Ne/He, O/He, and Ne/O abundances, to simulate the PUI production rate and count rate time series, and to calculate the corrections for ionization losses for the full sky maps of H ENA flux observed by IBEX. We studied the evolution of He, Ne, and O PUI count rate along Earth's orbit during the solar cycle and found differences in their evolution among the species. We concluded that the solar cycle variation in the density of the parent ISN species and in the ionization rates may cause a systematic shift in the flow direction of the ISN gas in the heliosphere derived from the analysis PUI measurements. We extended an existing software to model hypothetical departures of the distribution function of ISN He gas in the LISM from thermal equilibrium in order to study resulting signatures of these departures in the ISN He flux observed by the IBEX mission. We compared the results with the observations and concluded that the signal simulated for two different populations with the Maxwellian distribution function reproduces the data better than the kappa distribution function. We identified regions in the sky where the signatures from the signal given by the kappa distribution should be visible. The results of the study show that the modulation of the ionization factors inside the heliosphere due to solar activity is significant for the modeling of the ISN gas and its heliospheric particle populations and for the correct interpretation of the observations.