Heliospheric ENA fluxes: how sensitive are they to the ionization state of LIC?

Vlad Izmodenov (izmod@ipmnet.ru)
Moscow State Uinversity, Department of Aeromechanics, Faculty of Mechanics and Mathematics, Moscow, 119899, Russia

Mike Gruntman (mikeg@spock.usc.edu)
University of Southern California, Los Angeles

Vladimir Baranov
Institute for Problems in Mechanics, Russian Academy of Sciences, Moscow, Russia

Hans Fahr
Institut fur Astrophysik, Universitat Bonn, Germany

October 28, 2000

Abstract. We explore the sensitivity of the fluxes of heliospheric energetic neutral atoms (ENA) at 1 AU to the ionization state of the local interstellar cloud (LIC). The solar wind plasma is compressed and heated in the termination shock transition. The shocked solar plasma is convected toward the heliospheric tail in the heliosheath, the region between the termination shock and the heliopause. The ENAs are produced in charge exchange of the plasma protons and background neutral gas and can be readily detected at 1 AU. The expected ENA fluxes depend on the shocked plasma density, temperature, and velocity in the heliosheath. The size and structure of the heliospheric interface region depend on the parameters of the interstellar medium. ENA fluxes would thus reveal the LIC parameters. We demonstrate the sensitivity of the heliospheric ENA fluxes to the ionization state of the LIC. The axi-symmetric model of the solar wind/LIC interaction includes the self-consistent treatment of the plasma-gas coupling and Monte Carlo simulations of the neutral gas distribution.

Keywords: energetic atoms, solar wind, heliospheric interface, termination shock

1. Introduction

The local interstellar cloud (LIC) surrounding the solar system is partly ionized. The charged component of LIC efficiently interacts with the solar wind plasma forming the interface region. Interstellar H atoms penetrate the interface and coupled with the plasma component through charge-exchange. In the heliosheath - the region of the termination shock compressed and heated plasma - interstellar H atoms charge exchange with hot protons, which results in hot H atoms in the heliosphere. Some of these energetic H atoms penetrate as close as 1 A.U. to the Sun and can be measured as heliospheric ENAs. It was argued (see, e.g., Gruntman 1997; Gruntman et al. 2001) that the measurements of energetic neutral atoms (ENAs) can provide an excellent

Table I. Parameters of model calculations

SET	χ	$n_p + n_H, cm^{-3}$	n_H, cm^{-3}	n_p, cm^{-3}
A	5/6	0.24	0.04	0.20
B	5/12	0.24	0.14	0.10
C	1/6	0.24	0.20	0.04
D	1/3	0.30	0.20	0.1
E	1/2	0.40	0.20	0.2

diagnostics of the heliosheath plasma structure and, therefore, the nature of the termination shock.

The heliosheath structure strongly depends on the local interstellar parameters. In this paper we demonstrate the sensitivity of the heliospheric ENA fluxes to the ionization state of LIC. The ENA fluxes are calculated under assumptions of the axi-symmetric self-consistent model of the heliospheric interface.

2. Model

ENAs are born in charge exchange between the post-shocked solar wind protons and interstellar atoms. The directional differential ENA flux is a line of sight integral

$$j_{\vec{s},ENA}(\vec{r}_0,E) = \int_{R(TS)}^{R(HP)} j_p(s,E)\sigma(E)n_H(s)exp[-D(s,E)]ds$$

Here, $j_p(s,E)$ is the directional differential flux of protons in the heliosheath with the energy E, $n_H(\vec{r})$ is the local number density of interstellar H atoms and $\sigma(E)$ is the energy-dependent charge exchange cross section. The extinction of ENAs between points $\vec{r}$ and $\vec{r}_0$ is determined by $D(s,E) = \int(\beta_p + \beta_e + \beta_\nu)dt$, where the loss processes include charge exchange with the solar wind protons (rate β_p), electron-impact ionization (rate β_e) and solar photoionization (rate β_ν. The integration is performed along the atom trajectory with $dt = ds/(2E/m)^{1/2}$.

In order to obtain the heliospheric ENA fluxes, we compute $j_p(s,E)$ and $n_H(s)$ in the heliosheath using the self-consistent model of the heliospheric interface (Baranov and Malama, 1993; Izmodenov et al., 1999). The heliospheric interface structure is obtained for five sets of parameters. In all calculations, we used the same solar wind velocity, density and temperature and the LIC temperature and velocity relative the Sun. We varied interstellar proton and H atom number density (n_p and n_H, respectively). In set A through C

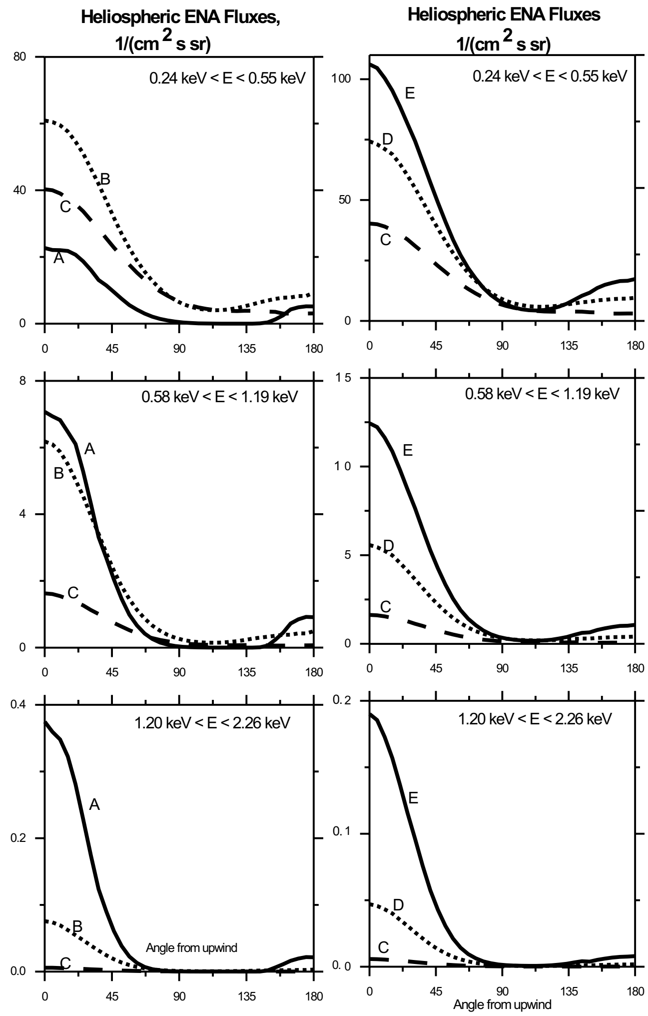

Figure 1. Heliospheric ENA fluxes in three selected energy bands as functions of angle *theta* calculated from the upwind direction.

(Table 1), we vary the interstellar ionization degree $\chi = \frac{n_p}{n_H + n_P}$ for a given total hydrogen number density $(n_p + n_H)$. Alternatively, we vary the interstellar proton number density n_p without changing the interstellar hydrogen number density n_p in sets C through E.

3. Results and Discussion

Figure 1 presents heliospheric ENA fluxes and local ENA productions in the heliosheath in three energy ranges: 0.24 - 0.55 keV, 0.58-1.19 keV, 1.20-

2.26 keV. These are the energy bands of a realistic ENA instrument for the heliosphere imaging space mission (Gruntman et al 2001). From analyses of the figure we conclude:

1. Generally, the ENA fluxes increase with the increase of the LIC ionization degree χ. In other words, the ENA fluxes *decreases* with the *increasing* interstellar H atom number density. This increase can be explained by the effect of the interstellar H atoms on the heliosheath plasma temperature. Particularly, the charge exchange of the hot solar wind protons with the cold interstellar H-atoms results in decrease of the plasma temperature. This effect is more pronounced for small values of χ.

2. There is a strong directional asymmetry of the ENA fluxes. The fluxes peak in the upwind direction. The minimum fluxes are expected at the angles $100^o < \theta < 150^o$ from the upwind. The relative asymmetry of the ENA fluxes becomes more pronounced with the increasing ENA energies. This dependence is valid for the range of the considered ionization states of the LIC (sets A-E). The asymmetry is the highest for the largest ionization degree, χ.

The presented results were obtained for only one of the possible scenarios of the post-shocked solar wind plasma. Our heliospheric interface model considers the original solar wind protons and the pickup protons as a single fluid. Other possibilities are discussed by Gruntman et al. (2001). Additionally, one could also expect to see at the Earth's orbit fluxes of the higher-energy (2-100 keV) ENAs produced by charge exchange of the preaccelerated pickup ions and anomalous cosmic rays.

Acknowledgements

This work was supported in part by U.S. Civilian Research & Development Foundation (CRDF) Award # RP1-2048, the Russian Foundation for Basic Research Grants # 98-02-16759, 99-02-04025, INTAS-CNES Grant # 97-512, the International Space Science institute (ISSI) in Bern, Russian-German cooperation project # 436 RUS 113/110/6 and the DFG project # FA 97/24-2.

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