PHYSICS OF THE OUTER HELIOSPHERE

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NEUTRAL SOLAR WIND EXPERIMENT

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INTRODUCTION

Interaction between ionized and neutral components of interstellar matter is a common process in the astrophysics. And our heliosphere in this case is no exception. The properties of the interacting neutrals are not in all respects well studied though they can serve as an indicator of important physical phenomena. One of such examples is the neutralized component of Solar Wind – i.e. the Neutral Solar Wind (NSW) – which originates by charge exchange of Solar Wind ions with neutral atoms in interplanetary space.

It was speculated that neutral atoms can be present in the Solar Wind as transients due to ejection of solar matter in violent events /1/. But only realization of the fact, that due to the substantial relative velocity of the Sun with respect to the surrounding Local Interstellar Medium (LISM) the interplanetary space is filled with neutral atoms of interstellar origin, led to the development of the concept of a permanently existing NSW. Solar Wind ions can capture electrons in collisions from neutrals thus giving rise to the NSW. Hence the velocity of NSW atoms equals that of Solar Wind. At first, it was believed that charge exchange only occurred between Solar Wind protons and interplanetary hydrogen /2/, and one could safely assume that at large distances from the Sun, the NSW consists of hydrogen atoms only. Later, however, it was recognized that charge exchange of protons with interplanetary helium atoms can provide comparable sources of NSW in the region within several a.u. from the Sun /3/. Finally, when it was realized in this context /4/, that the cross section for the simultaneous transfer of both electrons from interplanetary helium atoms to Solar Wind alpha particles is fairly high, it became clear, that helium atoms are also a non-negligible component of NSW close to the Sun.

NSW, which builds up gradually as Solar Wind ions travel further and further from the Sun, may play important role in shaping the global features of the interaction between the Sun and LISM. The most prominent of such features is the heliosphere itself. Some effects due to the NSW influence were already considered. Among them are i) transition from supersonic interstellar plasma flow to subsonic flow ahead of the heliospheric bowshock and thus pushing out the "last frontier" of the Solar system a few hundred a.u. further into interstellar space /5/, and ii) creation of anomalous hot component in the interstellar plasma flow with corresponding effects on interface region /6,7/.

THE NSW EXPERIMENT

By now there is no experimental information at all on NSW properties. That is why one may expect that the experiment to study NSW properties will give opportunity to test existing concepts about global interactions between neutrals and ions in Solar Wind plasma. The most feasible place for such an experiment is the Earth orbit, and further discussion thus will be restricted to this region. Serious experimental difficulties are responsible for the total lack of experimental measurements. The number density of NSW component is rather small ($< 10^{-4}$ cm^{-3} at Earth orbit) proving the conventional technique based on ionization and subsequent analysis of ions as unacceptable. However, these relatively high energy atoms can be detected by devices based on the effects of neutral particle interaction with surfaces, e.g. by secondary electron emission. The major obstacle to implement this technique is the highly superior background radiation in EUV (mainly in Lyman-alpha). EUV photons are counted also rather efficiently resulting in noise count rates several orders of magnitude higher than those expected from the NSW. Our attempt to study NSW uses the development of the experimental technique based on the coincidences realised by application of ultrathin foils and measurements of time-of-flight (TOF) of atoms in the instrument / 8,9,10 /. Such an approach is widely used in nuclear physics for identification of particles with much higher (at least by several orders of magnitude) energies.

The NSW experiment (included in the scientific package of GAS experiment to study fluxes of energetic neutral atoms in interplanetary space) is planned to be launched in the framework of the RELICT-2 mission scheduled for 1993. The spacecraft, after a three months cruise phase, will reach the collinear libration point L2 (Sun-Earth system) which is situated at the distance of $1.5\cdot10^6$ km from the Earth in antisunward direction. The spacecraft will perform then two revolutions around this point shifting at most $1.5\cdot10^5$ km from L2 in sun/antisunward direction, $8\cdot10^5$ km in perpendicular direction in ecliptic plane and $1.5\cdot10^5$ km out of ecliptic. Period of each revolution is 6 months. The spacecraft will be spinning around an axis pointed at the Sun. The NSW instrument will be looking at the off-set angle 6° from the spin axis - i.e. scan a ring around the Sun. The instrument field of view is 4°x4°. Spacecraft trajectory gives opportunity to measure NSW itself and also, in certain parts of the trajectory, neutrals originating in charge exchange of Solar Wind ions with the terrestrial exosphere, as well as energetic neutral atoms from terrestrial magnetosphere.

For the observer moving together with the Earth along its orbit around the Sun the average direction of NSW will be shifted 4-5° from the direction to the Sun due to the aberration. Detailed computer simulations /10/ show that the expected NSW flux is in the range 10^3 - 10^5 cm^{-2} s^{-1} sr^{-1} depending on the parameters of interstellar gas as well as on the position of the observer at Earth orbit.

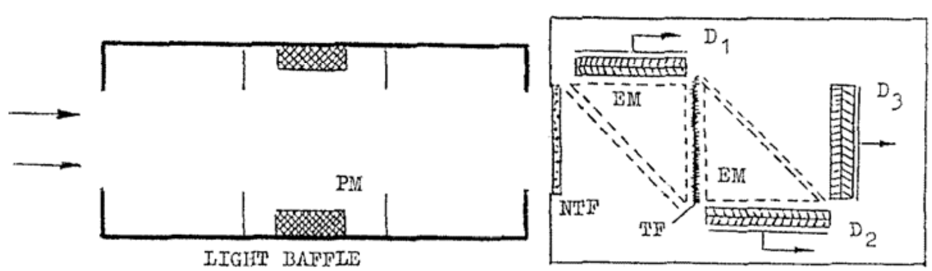

Fig.1. Neutral solar wind detector-energy analyser. D_1,D_2,D_3 - microchannel plate detectors; TF - thin foil; EM - electrostatic mirrors; NTF - nuclear track filter (optional); PM - permanent magnet.

INSTRUMENT FOR NSW DETECTION

The instrument to study NSW (sensor GAS-2 within GAS instrument package) is shown in Fig.1. A solar baffle prevents illumination of the sensor by photons from the Sun directly. Permanent magnets deflect charged particles with energies up to 30-50 keV. When a background UV photon comes to the instrument, it may be either absorbed by the thin carbon foil (with possible emission of electron followed by its acceleration by the nearest grid of electrostatic mirror and by the triggering of detector D_1 or D_2), or it may penetrate through the foil and impinge on (with possible triggering) detector D_3. The foil is 80 Å thick and its diameter is 27 mm. Detectors are built as chevron stacks of microchannel plates. Arrival of the neutral particle may, on the other hand, result in both above mentioned "simultaneous" events, i.e. emission of electrons from the foil and triggering detector D_3. Hence the particles can produce coincidences (time gate 250 ns) which give opportunity to extract the very weak signal due to NSW from the superior background count rates / 8,9,10 /. Also time intervals between pulses from D_1 (D_2) and D_3 are measured, and accumulated TOF spectrum contains information on velocity distribution of the incoming atoms. Typical TOF spectra obtained by the instrument, when registering (in laboratory) monoenergetic hydrogen atom fluxes, are shown in Fig.2. The energy resolution is $E / \Delta E = 2$. Detection efficiency (i.e. probability of coincidences) of the instrument goes down from 20 to 1-3 % with the decrease of registered atom energy from 3000 eV to 600 eV. Detailed estimates based on the expected fluxes of both NSW and UV photons show that NSW can be successfully studied / 10 /.

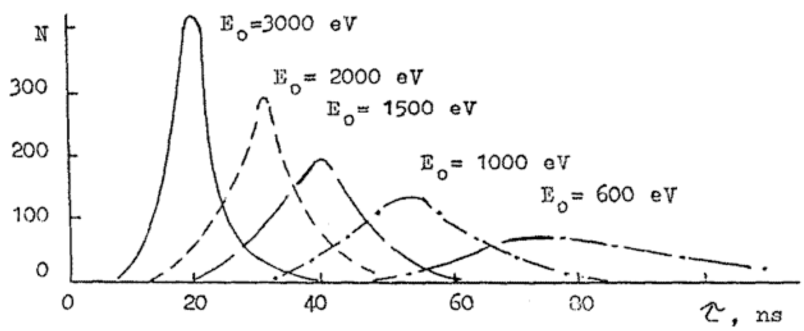

Fig.2. Typical time-of-flight spectra for the detection of monoenergetic (E_o) hydrogen atom fluxes.

It should be mentioned that a nuclear track filter (NTF), which is optional, though reducing 10-20 times absolute value of NSW flux in instrument, increases the ratio of neutrals to UV photons from 3 to 6 orders of magnitude at the sensor entrance. The use of NTF to filter neutrals from photons was proposed in / 9,10 / and it is still under development. The NTF will consist of 1 μm thick film with parallel straight channels (1000 Å diameter) and geometrical transparency 4-10 %.

ENERGETIC NEUTRALS FROM THE HELIOSPHERIC INTERFACE

Solar Wind plasma after passage through the inner shock is in a rather hot state. Due to the charge exchange of its protons on inflowing interstellar gas, this region is an extended source of energetic (0.2-0.8 keV) neutral hydrogen atoms. According to present estimates / 7 /, the expected flux number density is 10^2 cm^{-2} s^{-1} sr^{-1} at Earth orbit. There is another sensor - GAS-3 - in the GAS package of Relict-2 mission. It is identical to GAS-2 except for the baffle which is much simpler and smaller and defines a field of view of 15° x 15° . GAS-3 is pointed in antisunward direction and its main purpose is to try to detect the energetic neutrals from the interface region. Giant planets, Jupiter and Saturn, when in the instrument field of view, may give also detectable count rates due to fluxes of energetic neutral atoms from their magnetospheres.

EXPECTED SCIENTIFIC RETURN

The Neutral Solar Wind experiment will be the first attempt specially dedicated to the study of fluxes of energetic neutral atoms in heliosphere. It will give opportunity to test by a qualitatively new way our basic ideas about interaction (and its consequences) between neutrals and plasmas of Solar system and LISM. Measurements of NSW may lead to determination of interstellar gas parameters, concentration of the interplanetary dust around the Sun and Solar Wind characteristics at distances <0.4 a.u. to the Sun. Detection of the energetic neutral atom flux from the interface region may be the first direct evidence of the existence of the widely discussed termination shock and heliospheric structure in general. The experiment may also provide new information on the magnetospheres of the planets like Earth, Jupiter and Saturn. The latter may lead to a rather promising approach to the remote study of magnetospheres of giant planets.

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