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Study of particle acceleration mechanisms in the anisotropic solar wind

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Abstract

Compton and inverse Compton effect in solar wind plasma, equations obtained on the basis of magnetohydrodynamic theory for one-particle plasma were investigated. The radial dependences of the solar wind speed were obtained and analyzed using MHD equations. The results are important in explaining the acceleration mechanism of cosmic plasma particles, in studying the evolution process of the Sun and stars, as well as in the study of the factors affecting the operation of radio electronic control devices.

Keywords: Solar wind, magnetohydrodynamics, Compton effect, cosmic plasma, sun.
PACS: 52.30.Cv; 95.30.Qd; 96.25.Qr; 96.50.Ci

1. Introduction

Current issues in astrophysics include how the sun and other stars create a strong magnetic field that changes periodically, whether this process has different and similar aspects in objects, how much the temperature of the corona is greater, and other issues. [1]. The influence of the solar wind on the Earth makes the study of cosmic plasma and the solar wind relevant: the formation of geomagnetic storms, depending on the intensity of the solar wind plasma, control devices, ground complexes, flying machines and control systems, remote control systems, radio engineering, radio navigation, radar and television systems and devices, navigation and air traffic control, micro- and nanoelectronic devices are not unaffected. Launched on August 12, 2018, the Parker probe will study the Sun, the structure of the solar

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wind, and the dynamics of the magnetic field, find the energy levels of the solar wind radiated and accelerated by the solar corona, and study the mechanism of particle acceleration to form the circumsolar plasma and their interaction with the solar wind. aimed at. [2].

Applying the Compton effect to the electrons and protons in the solar wind plasma, it is possible to explain the process of particle acceleration in this sense: the energy of electrons in the solar wind plasma is 2 MeV, the energy of protons is 10 MeV, and so on. Depending on the ignition, the energy of this or that particle can change. Depending on the energy of the photon radiation, Compton and inverse Compton processes can be applied to the anisotropic solar wind. In the inverse Compton effect, the energy of the photon scattered by the relativistic particle increases, and as a result of the Compton effect occurring with the next protons, the acceleration of the proton occurs. With this, the process of transferring the energy of electrons to protons takes place. Taking this into account, the energy of photons increases more in this process at larger values of electron energies. In cases where space objects radiate electrons, the deviation of spectral lines should be observed and is observed [3]. It is necessary to take into account magnetogravitational waves and their hybrid mixtures in the transmission of energy [4].

Solar wind dynamic, physical parameters: density, speed, magnetic field induction, etc. varies over time and space in a wide range. The existence of these changes indicated that the coronal expansion is not a stationary homogeneous plasma flow as originally imagined by Parker, but a very complex process [5].

Characteristic measurements of time range from fractions of a second (plasma waves, "noise"), tens of hours, and diurnal (variation due to large-scale changes in the solar corona's inhomogeneity and structure).

First, the fluid dynamics in collisionless plasma was considered, the magnetohydrodynamic approximation was made, and then the problems were considered taking into account thermal effects. Radial and stationary flow from the Sun is treated with isotropic MHD equations. Examining problems without considering heat fluxes has not proven to yield correct solutions [5].

2. Basic educations

The problem is considered for the stationary case in spherical coordinates. Radial propagation of plasma for magnetic field induction B_ϕ = 0 və V_ϕ = 0, parameters are taken as dependence on radial distance. B= B_r, h_r = 1, h_ϕ = 0, In the [6],

$$r^2 B = C_1, r^2 \rho V = C_2, \tag{1}$$

$$\frac{V^2}{2} + \frac{1}{\rho}\left(P_\perp + \frac{3}{2}P_\parallel\right) + \frac{1}{\rho V}\left(S_\perp + \frac{1}{2}S_\parallel\right) - \frac{GM}{r} = \frac{C_5}{C_2}, \tag{2}$$

$$r^4(p_\perp V + S_\perp) = C_1 C_6, \tag{3}$$

let's replace the constants. $u_\parallel^2 = p_\parallel/\rho$ və $u_\perp^2 = p_\perp/\rho$ are thermal velocities. If we move to unitless quantities

$$\left(\frac{Y}{X} - 1\right)\frac{dX(x)}{dx} - 2\frac{dY(x)}{dx} + \frac{4}{x^3}Z(x) - \frac{2\bar{g}}{x^2} = 0 \tag{4}$$

$$\left(\bar{C}_6 - Z(x)\right)\frac{dX(x)}{dx} + \left(Y(x) - X(x)\right)\frac{dZ(x)}{dx} - \frac{2}{x^3}Z^2(x) = 0 \tag{5}$$

$$\left(\frac{Y(x)}{X(x)} - 1\right)\frac{dY(x)}{dx} + \frac{4}{3}\left(\bar{C}_5 + \frac{\bar{g}}{x} - \frac{\bar{C}_6}{x^2} - \frac{3}{4}X(x) - \frac{3}{2}Y(x)\right)\frac{1}{X(x)}\frac{dX(x)}{dx} +$$

$$+\frac{2}{3x^2}\left(\frac{2\bar{C}_6}{x} - \bar{g}\right) = 0, \tag{6}$$

there

$$3r^3\frac{dX(x)}{dx} + \frac{f_1(x)}{f(x)} = 0, 6r^3\frac{dY(x)}{dx} + \frac{f_2(x)}{f(x)} =$$

$$= 0, 6x^3 X(x)\frac{dZ(x)}{dx} + \frac{f_3(x)}{f(x)A(x)} = 0 \tag{7}$$

and

$$x = \frac{r}{R}, X = X(x) = \frac{V^2}{v_0^2}, Y = Y(x) = \frac{u_\parallel^2}{v_0^2}, Z = Z(x) = x^2\frac{u_\perp^2}{v_0^2}, \bar{C}_5 = \frac{C_5}{C_2 v_0^2},$$

$$\bar{C}_6 = \frac{C_1 C_6}{C_2 R v_0^2}, \bar{g} = \frac{G M_0}{R v_0^2},$$

$$A(x) = \frac{Y(x)}{X(x)} - 1, B(x) = \frac{3}{4}\left(K_1(x) - 3X(x)\right), K_1(x)$$

$$= \frac{4}{3}\left(\bar{C}_5 + \frac{\bar{g}}{x} - \frac{\bar{C}_6}{x^2}\right),$$

$$D(x) = 2Z(x) - xg, \qquad E(x) = 2C_6 - xg, \tag{8}$$

$$f(x) = \frac{A(x)}{2}(A(x) - 4) + \frac{4B(x)}{3X(x)}; f_1(x) = 3A(x)D(x) + 2E(x), \tag{9}$$

$$f_2(x) = A(x)f_1(x) - 6D(x)f(x),$$

$$f_3(x) = f_1(x)\left(D(x) - E(x)\right) - 12f(x)Z(x)^2. \tag{10}$$

3. Obtained results

The received system of equations (4) programmed by numerical methods, the radial dependencies of X, Y and Z parameters were investigated around the singular point (x=1, X=Y, A=1). It is established that the equation has not one but several singular points. Near these points, the values of the X parameter increase sharply. In other cases, problems were considered for extremely small cases of X, Y, Z parameters, and special solutions were obtained [7].

Other physical processes in the solar wind must also be taken into account: taking these processes into account in their entirety creates mathematical difficulties. Thus, the Compton effect, reverse Compton effect, and double Compton effects play a role in the acceleration of solar wind particles. Large enough energies of electrons lead to an increase in the energy of photons involved in these processes. When cosmic sources contain electrons and other particles and their energy exceeds the energy of photons, in this case the propagation of primary spectra occurs. Photons, electrons, protons and other particles radiating from the sun interact and participate in KE and TKE processes. Photons scattered from the electron are absorbed by the protons, causing them to accelerate: scattering of photons from high-speed electrons increases their energy, and these photons are absorbed by the protons. As a result, the speed of ptorons increases. This process plays a role in the acceleration mechanism of particles in cosmic plasma. The study of Compton effects in space plasma, among other processes, provides an opportunity to study solar plasma and then continue the study.

Figures 1.a and 1.b show the dependence of the dimensionless quantity X(x) on the distance from the Sun, which will determine the speed of the solar wind. Curves in blue show asymptotic solutions. The red lines are the curves obtained as a result of calculations: the red line given in Figure 1.a is for the case A=0, X=Y, and the red line given in 1.b is the curve obtained for A=4, Y=5X. In both cases, it decreases with increasing distance from the sun. This corresponds to the current physical state of the solar wind at the heliosphere boundary, where it encounters the stellar wind at very large distances.

In Figure 2, the X(x) quantity characterizing the speed of the solar wind is determined by the expression (8) from the equations (4)-(6) and the graphs of the dependence of the parameter A on the distance x are determined for the mass near the Sun at different values.

$$x = \frac{r}{R}, A(x) = \frac{Y(x)}{X(x)} - 1, X = X(x) = \frac{V^2}{v_0^2}.$$

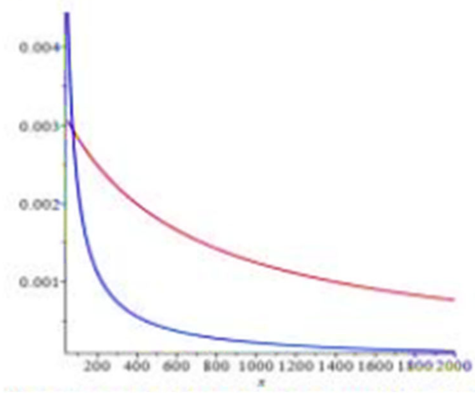

Fig. 1a.

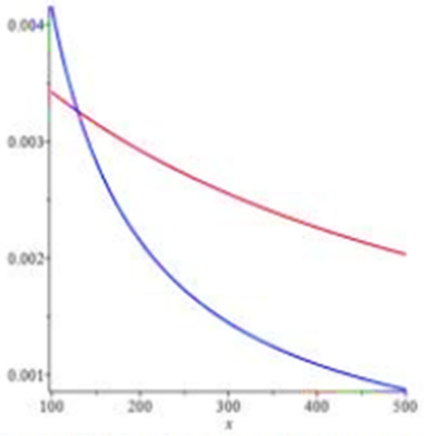

Fig. 1b.

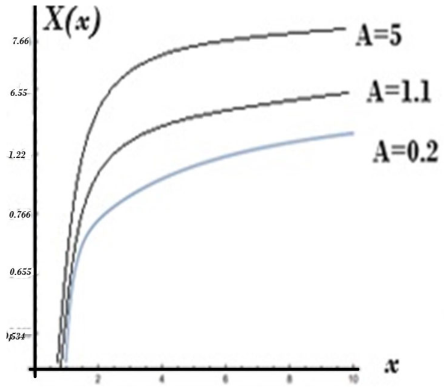

Fig. 2

4. Discussion

The distance x is given to include dimensionless quantities. Its physical nature is determined from the determined solutions. r- is the distance from the sun. It can be seen from the graphs in Figure 2 that the value of the quantity X(x) characterizing the solar wind starts from the point x=1. It was bought as such for all special occasions. From here, it is possible to give the physical meaning of the quantity R: since the solar wind originates from the surface of the Sun, it is created due to coronal mass ejections, so the distance R can be taken as the radius of the sun or the distance from the center of the sun to a middle point where coronal mass ejections occur. Thus, the quantity R carries the essence of the distance from which the solar wind starts. This distance can be taken as the radius of the Sun at first approximation.

İn figur 2.a A=1, in 2.b A=0.2 and in 2.c A=5.

As it moves away from the Sun, the speed of the solar wind plasma first increases and then remains constant starting from a certain distance, and decreases near the heliosphere. From the graphs in Figure 2, it can be seen that the speed of the solar wind increases sharply at first, and then this rate of increase weakens. Since the equations written for the solar wind do not show the heliospheric boundaries and do not take into account the effects of extrastellar winds, this speed will simply increase in the graphs. Although this dependence is determined for different cases of A as a coefficient characterizing the ratio of the heat movement speed of solar wind particles perpendicular to the radial direction of movement to the wind speed, the graphs start from the same point at the distance x=1, R=r.

Mechanisms for the acceleration of the solar wind after separation from the sun are included in the mission of the Parker Solar Probe satellite launched from Earth in 2018. If we take into account the obtained graphs, one of the mechanisms of the increase in the speed of the solar wind particles is that the wind carries the magnetic field after leaving the sun, obeys magneto-hydrodynamic processes and laws. Although the obtained graphs cannot fully characterize the state of the solar wind plasma, they allow us to analyze the distance dependence of the wind speed at certain distances. The obtained solutions are important for the complete study of the radial dependence of the solar wind parameters. Depending on the intensity of the solar wind plasma, control devices, ground systems, flying machines and control systems, remote control systems, radio engineering, radionavigation, radar and television systems and devices, navigation and air traffic control, micro and nanoelectronic devices are unaffected. From this point of view, the study of the solar wind, the study of the change of its parameters according to time and space is appropriate at the present time.

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