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SOLAR CORONA EXPANSION AND HELIOSPHERIC CURRENT SHEET CREATION

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Abstract. Heliospheric current sheet creation has been investigated by numerical solution of 3D MHD equations, using the Peresvet code. The dipole magnetic field is corresponding to the solar activity minimum, and typical corona parameters are used as initial conditions. Plasma compression, dissipation, thermal conductivity, and gravitation are taken into account. Polarization does not appear at radial expansion of the solar corona. As a result, $\mathbf{E}=0$ in the sheet, and the current density becomes as $\mathbf{j} = \sigma\mathbf{V}\times\mathbf{B}/c$. The normal magnetic field component is an important feature of the heliospheric current sheet. The sheet can not be a neutral one. Current generation is similar to action of a short closed MHD generator. The solar wind temperature is determined by plasma cooling because of plasma expansion and heat conduction from the Sun. In the process of expansion the solar wind is accelerated and achieves the supersonic velocity at a distance of about 3 solar radii. The stationary plasma flow is very sensible to corona parameters. The current sheet is surrounding by a thick plasma sheet, but plasma velocity is dropped inside the sheet. It is shown that the upper limit of the solar wind conductivity is determined by the current velocity limit.

Introduction

Corona thermal expansion takes place in presence of gravitation and solar magnetic field. It is possible to select an integration constant in the motion equation so, that the acceleration works continuously [1], and the supersonic velocity is achieved at some critical distance from the Sun. This result has been obtained in isothermal approximation, the heat conductivity anisotropy in the magnetic field is not taken into account. It is difficult to excuse the isothermal condition, because the corona temperature is ~200 eV, and the solar wind temperature at the Earth orbit is ~20 eV. These restrictions are absent in the presented numerical experiment.

The solar corona expansion produces super sonic plasma flow – solar wind and Sun magnetic field lines stretching. The magnetic field configuration is mostly determined by the current in the closed heliospheric current sheet located near the ecliptic plane. The possible magnetic field configuration has been the first time considered in a two dimension approximation [2]. The gravitation is neglected. However, the necessity of a neutral line existence is assumed. This assumption is difficult to ground. The authors of [2] claim absence of a normal magnetic component in the current sheet and existence two classes of magnetic field lines (closed and opened). These conclusions are very doubtful. The mistaken conclusion about absence of normal magnetic field component in the heliospheric current sheet is obvious. There are no possibilities to generate current in a stationary neutral ring current sheet. For current generation it is necessary to have conductive liquid flow across the magnetic field. The Ohm low in MHD approximation is $\mathbf{j}/\sigma = \mathbf{E} + \mathbf{V}\times\mathbf{B}/c$. The polarization electric field $\mathbf{E} = -\mathbf{V}\times\mathbf{B}/c$ appears only during restricted conductor motion across the magnetic field because of $j = 0$. As a result the electric charges of opposed polarity are induced at the conductor edges. In the ring current at radial expansion of the solar corona the charges move freely under Lorenz force action, and polarization does not appear. The current density becomes as $\mathbf{j} = \sigma\mathbf{V}\times\mathbf{B}/c$. There are no others possibilities for a stationary ring current generation. The ring current sheet appears only in the presence of a normal magnetic field component B_n. The current value in such generator is determined by its internal resistance. Existence of B_n means that magnetic lines can not be divided in closed and opened, as it has been proclaimed in [2]. All field lines that come out of one solar hemisphere enter the other hemisphere crossing the current sheet.

The results of numerical MHD calculations for stationary solar wind [3] carried out with typical simplification contradict to [2]. They show existence of a normal magnetic component in the heliospheric current sheet.

In our recent 3D MHD calculations thermal expansion of the solar corona was performed [4, 5]. The modern Peresvet code was used. The results show that the current sheet is not a neutral one, but possesses a normal magnetic field component. This component is responsible for ring current generation in the course of corona expansion. Here we present some data concerning supersonic solar wind creation and the main characteristic of heliospheric current sheet, including normal magnetic field component.

Numerical methods

The Peresvet code is used for solving the system of resistive 3D MHD equations for compressible plasma [5, 6]. Solar gravitation and anisotropy of the thermal conductivity are taken into account. Implicit scheme, that is conservative relative to the magnetic flux, permits to avoid errors connected with numerical div**B** approximation. The calculations carried out in the box $8R_{\odot}\times8R_{\odot}\times8R_{\odot}$ with the net 41×41×41. The scheme of calculation in the plane $Y=4R_{\odot}$ is shown in fig. 1. Coronal plasma flows from the circle (in the plane X=0) with radius $R_{\odot}$. The point Y=0.5, Z=0.5 is the center of the circle. This point is situated in $1.7R_{\odot}$ from the Sun center. Parameters of corona in the plane X=0 are following: density $\rho=2\times10^{7}$ cm^{-3}, magnetic field B=0.15 G, and velocity $V=4\times10^{6}$ cm/s, corresponding to solar mass escaping. The solar dipole magnetic field is corresponding to minimum solar activity (B~0.8 G on the solar equator). Magnetic field lines of the undisturbed dipole are shown in fig. 2a. At t=0 very low density ($\rho=0.1$ cm^{-3}) is set in all calculation region. It is necessary because the vacuum medium can not be described in MHD approximation. Such low initial density almost does not influence on the plasma dynamics.

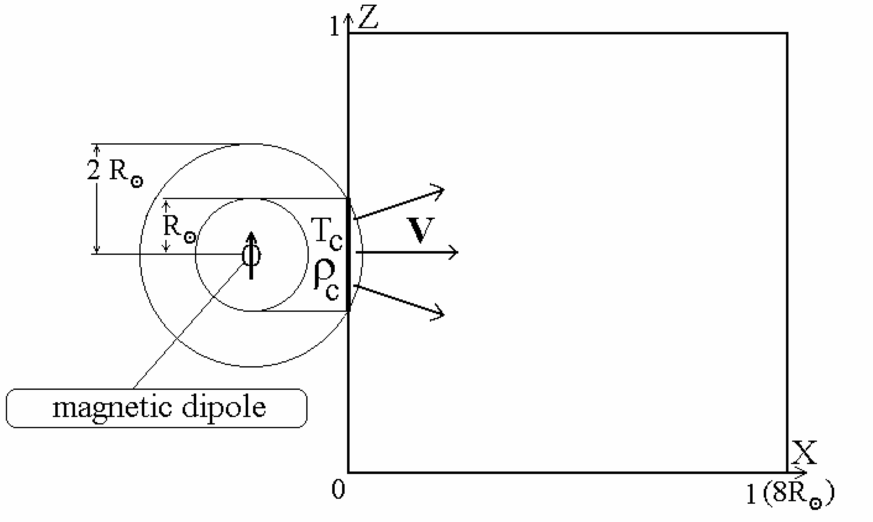

Fig. 1.

Results

The initial magnetic field lines (dipole field corresponding to solar activity minimum) are shown in fig 2a. Calculations demonstrate that coronal plasma expansion disturbs the magnetic field of solar dipole and creates a current sheet in the equatorial plane. Magnetic field lines stretched due to plasma expansion are seen in fig. 2c and 2e. Fig. 2e shows the lines that correspond to achievement of the stationary configuration. Here magnetic field configuration is determined by superposition the dipole and current sheet fields. There are no opened field lines in this configuration, all lines connect North and South hemisphere. All lines cross the current sheet, e. g. current sheet possesses the normal magnetic component. The velocity increases with distance from the Sun.

The results of calculation shown in Fig. 2 demonstrate that at beginning of calculation gradients of density (n) and temperature (T) are very sharp at the left boundary, and the ∇p is much bigger then gravitation force. At the beginning, plasma acceleration takes place near the left boundary, where ∇p is not zero. The maximum velocity is reached inside the calculation region. At $t=3.3\times10^{3}$s (fig. 2c) field lines stretched near the left boundary, but at the right boundary magnetic lines have shape of not disturbed dipole field. The temperature gradient is not as sharp as the density gradient, because of heat conduction. The gradients decrease with time, but the region where $\nabla p\neq0$ increases. During corona expansion the ∇p force decreases. The velocity maximum drifts from the Sun. At $t\sim1.5\times10^{4}$s it reaches the right boundary. The stationary flow is achieved at $t\sim4\times10^{4}$s (Fig. 2e). The plasma flow transfers into a supersonic solar wind at $X\sim0.8R_{\odot}$, that distance corresponds to the radial distance of $\sim2.5R_{\odot}$ from the Sun center. There are no discontinuities appeared near this point. A current sheet generation in the equatorial region of the all calculation region takes place.

The current sheet is very narrow; it is located inside the rather broad plasma sheet. Plasma velocity is dropped inside the sheet because of braking by **j**x**B** force. The similar situation is revealed in the space measurements [8].

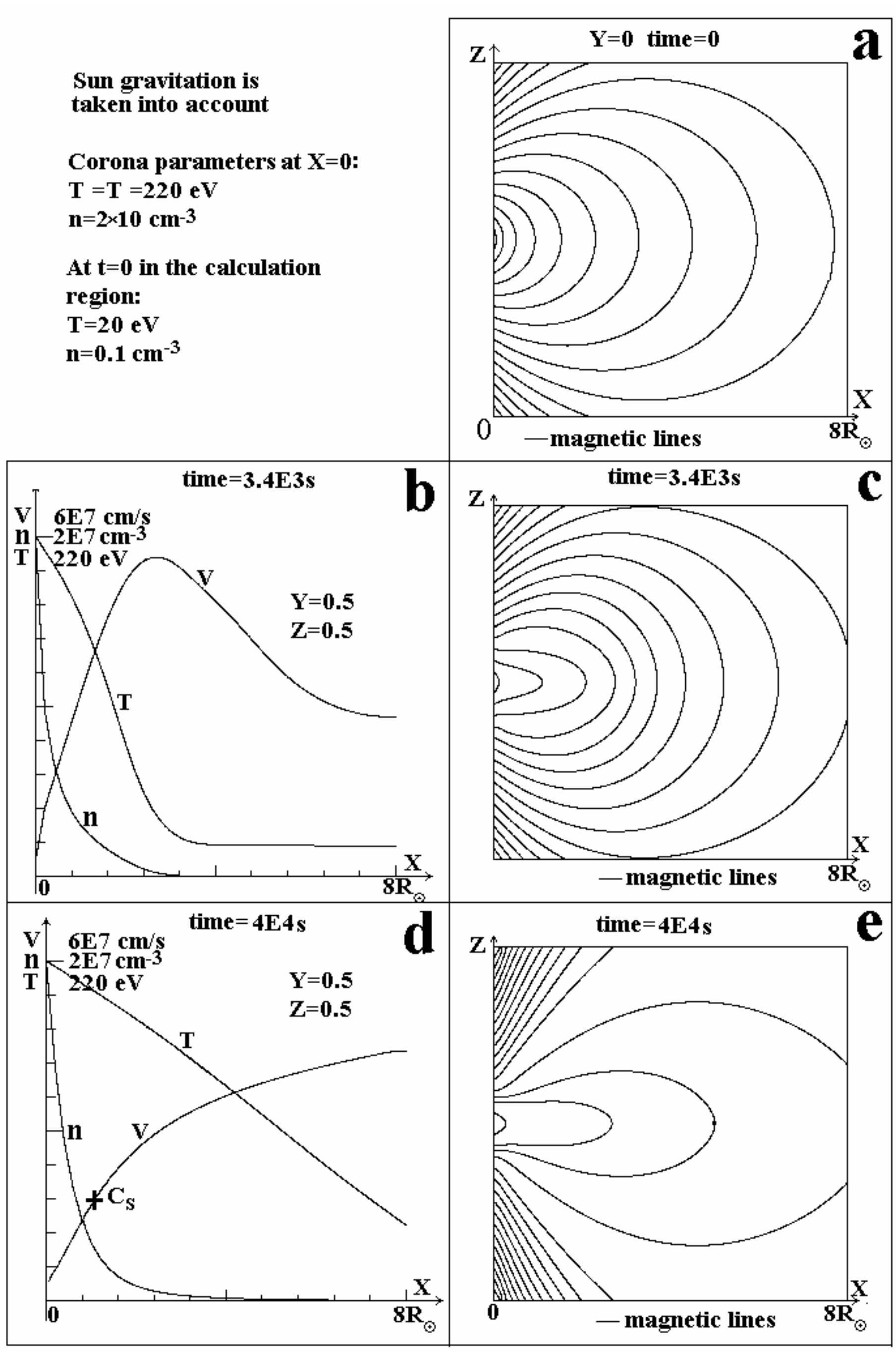

Fig. 2.

The upper limit of solar wind conductivity

The magnetic field configuration in the solar wind is determined by magnetic field transfer with conductive media and field diffusion: $\frac{\partial B}{\partial t} = rotV \times B + \frac{c^2}{4\pi\sigma}\Delta B$. In the stationary condition: $\frac{\partial B}{\partial t} = 0$. The radial component of the equation along the sheet can be written as $VB_{\perp} \sim \frac{c^2 B}{4\pi\sigma\delta}$. The current sheet thickness δ is ~10 cm at the conductivity $\sigma_0 = 1.1\times10^{13} T_e^{3/2} \sim 10^{15}$ 1/s, the solar wind velocity $V = 5\times10^7$ cm/c, and the ratio of normal component to the interplanetary magnetic field $B_{\perp}/B$ ~100. Using $rotB = \frac{4\pi j}{c}$ one can estimate the current drift velocity as $V_d = \frac{j}{en} \sim 10^{13} cm/s.$ These estimations show that the Spitzer conductivity $\sigma_0 \sim T^{3/2}$ can not be used for a thin current sheet in low density space plasma. Apparently, V_d is restricted by instability development. The beam instability appears at $V_d \sim (kT_e/m_e)^{1/2} \sim 2\times10^8$cm/s. The ion sound instability can manifest itself even at $V_d \sim (kT_e/m_i)^{1/2} \sim 5\times10^6$cm/s. It appears if $T_e >> T_i$. The maximum current density should be 2×10^6 times less. The conductivity has to be order of $\sim10^{-6}\sigma_0$, and real heliospheric current sheet thickness is order of $\sim10^7$ cm.

These estimations demonstrate that using the Spitzer conductivity in the solar wind is not always correct. Electron current velocity V_d = j/ne in the current sheet obtained from the Ohm low using the Spitzer conductivity $\sigma_0 \sim T^{3/2}$ can surpass its possible maximum value in a low density plasma. In the solar wind the j_{max} is restricted by beam instability development. This local effect may reveal itself in other regions where V_d reaches the critical value. It can be responsible for the limit of ∇B in different magnetic structures. The maximum current density can not be bigger than of 10^{-11} A/cm^2.

It should be pointed out that **j**×**B**/c force is much less than gravitation and pressure gradient forces.

Conclusion

Analysis of corona expansion in presence of gravitation and solar magnetic field shows:

1. Thermal corona expansion produces the supersonic solar wind with a heliospheric current sheet that possesses the normal magnetic field component.
2. Current generation in the heliospheric current sheet is similar to current production in the short closed MHD generator.
3. Solar wind transfer into supersonic flow occurs at ~2.5 solar radii.
4. In regions of high electric field, such as HCS, the real solar wind conductivity can be order of 10^{-6} of Spitzer conductivity.

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