Estimation of the Three Components of the Solar Wind Energy Throughout the Solar System

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Abstract. Approximately at 1.5 solar radii above the solar surface, the Sun's coronal magnetic field is forced open into the heliosphere by the outward pressure of plasma. This region represents the starting point of the solar wind into the interplanetary medium, as every second the Sun continually ejects into the space a huge amount of mass. This ejection carries a very small fraction of the solar energy output but it has a significant importance to the physics in the solar system. The total energy carried by the solar wind plasma is the sum of three energy components – magnetic energy, thermal (internal) energy and flow (kinetic energy). The energy of the solar wind causes numerous processes and phenomena. The goal of the present paper is to give an estimation of these three components of the solar wind energy through the Solar system.

Keywords: solar wind energy, kinetic energy, magnetic energy, thermal energy

Introduction

In the last decades our understanding about the solar wind (SW) energy has spawned a big progress. This is largely due to observations made by a couple of spacecrafts (Voyager 1 and 2, Ulysses, SOHO, etc.). A number of measurements made by these spacecrafts show that SW must be divided into two distinct states depending on the properties of its basic parameters (McComas et al., 2003). The first state is the fast solar wind (FSW), which is characterized with speed of about 700-800 km/s. FSW originates from coronal holes (near the Sun's poles and holes which appear in different latitudes of the Sun's disk). The second state is the slow solar wind (SSW) with average speed of about 350-450 km/s. SSW emerges from smaller and less permanent structures. However, the details of the source region and mechanisms are still under investigation.

Except the average speed in these two types of SW, there are also differences between other parameters (density, electron and proton temperature, magnetic field, Alfen speed, etc.). On the other hand SSW is highly variable and filamentary while FSW is more uniform displaying slower changes with time.

Approximately at 1.5 solar radii above the solar surface, the Sun's coronal magnetic field is forced open into heliosphere by the outward pressure of plasma. These regions represent the starting point of the SW into the interplanetary medium. Through its movement the SW transfers energy from the Sun to the Solar system. Furthermore, because of the various parameters values, FSW and SSW carry different amount of energy and after interaction with some interplanetary or planetary environments these two types of SW can cause a diversity of processes and phenomena.

The main goal of this work is an estimation of the energy density carried by the SSW throughout the Solar system.

Three components of the SW energy

Every second the Sun continually ejects into the space a huge amount of mass. This ejection carries a very small fraction of the solar energy output but it has a significant importance to the physics in the solar system. The total energy carried by SW plasma is the sum of three energy components – magnetic energy, thermal (internal) energy and flow (kinetic energy).

The energy density of the SW's magnetic field is:

$$E_M = \left\langle \frac{B^2}{2\mu_0} \right\rangle_{SW}, \tag{1}$$

where B is the magnetic field strength in nT and μ_0 is the permeability of free space. The thermal energy density can be estimated by:

$$E_T = \left\langle \frac{3}{2} nk(T_e + T_i) \right\rangle_{SW}, \tag{2}$$

where Te is SW electron temperature, Ti is SW ion temperature, n is SW density in particles/cm^3 and k is the Boltzmann constant. The flow energy density is estimated to be:

$$E_F = \left(\frac{1}{2} \rho v^2 \right)_{SW} \approx \frac{1}{2} m_p n v_{SW}^2, \tag{3}$$

where m_p is the mass of the proton and v_{SW} is the speed of the SW in km/s.

Estimation of SW energy density

Adopting typical SW values for the density, speed, magnetic field strength, electron and ion temperatures in (1-3), we can estimate the expected 3 components of the energy density (J/m^3) of SW for the corresponding distance. In Table 1 some typical values of SW parameters near the planets of the Solar system are presented (Holzer, 2005; Feldman et al, 1977; Bagenal, 2009). Here the density fluctuates by about a factor of 5 around typical values.

For the estimation of the SW energy density typical SSW condition with average SW speed v_{SW} ~ 400 km/s which corresponds to the values in the Table 1 is used (Walker and Russell, 1995). In Table 2 and Figure 1 are shown the main estimations of the three components of SW energy. For the calculation of the thermal energy E_T SW temperature profiles from Smith et al. model are used (Smith et al., 2001; Richardson and Smith, 2003).

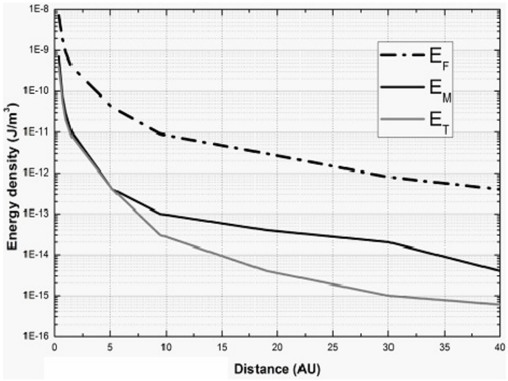

Figure 1 Three components of tehe energy density of the solar wind-flow: E_F, magnetic energy: E_M and thermal energy: E_T

Figure 1 presents the three components galactic distribution of energy density of the solar wind. The estimations are calculated to 40 AU (Pluto's orbit). As it can be seen all three components vary significantly with distance. The typical values of the flow (kinetic energy) E_F near Mercury's orbit are about 1E-8 J/m^3 and 1E-13 J/m^3 near Pluto's orbit (reduction of more than five orders). Other two components (magnetic energy E_M and thermal energy E_T), which have typical values of 1E-9 near Mercury's orbit have similar values to Jupiter's orbit and after that they separate from each other significantly. At Pluto's orbit E_M decreases to about 5E-15 J/m^3, while E_T reaches values approximately 5E-16 J/m^3.

One important note for the presented results is that the estimations are made in absence of any space objects such like magnetospheres, atmospheres, etc., which could cause some disturbances of SW parameters

Conclusions

After estimation of the energy density it can be seen in Figure 1 that the energy of the solar wind is dominated by the flow throughout the Solar system – flow controls the magnetic field and the thermal energy density has the smallest value. The theoretical way to deal with this is to treat the flow in gas dynamic approximation and to neglect the magnetic field

Table 1. Typical values of SW density and magnetic field strength near the planets of the Solar system

	Merc.	Venus	Earth	Mars	Jupiter	Saturn	Uran.	Nept.	Pluto
Distance (AU)	0.39	0.72	1	1.52	5.2	9.5	19	30	40
SW density (cm^{-3})	53	14	7	3	0.2	0.07	0.02	0.006	0.003
Magnetic field strength (nT)	41	14	8	5	1	0.6	0.3	0.2	0.1

Table 2. Estimation of the three components of SW energy - magnetic energy E_M, thermal energy E_T, and flow (kinetic energy) E_F near the planets of the Solar system

	Merc.	Venus	Earth	Mars	Jupiter	Saturn	Uran.	Nept.	Pluto
EF (J/m3)	7×10^{-9}	2×10^{-9}	9×10^{-10}	4×10^{-10}	4×10^{-11}	9×10^{-12}	3×10^{-12}	8×10^{-13}	4×10^{-13}
EM (J/m3)	7×10^{-10}	8×10^{-11}	3×10^{-11}	1×10^{-11}	4×10^{-13}	1×10^{-13}	4×10^{-14}	2×10^{-14}	4×10^{-15}
ET (J/m3)	4×10^{-10}	6×10^{-11}	2×10^{-11}	8×10^{-12}	4×10^{-13}	3×10^{-14}	4×10^{-15}	1×10^{-15}	6×10^{-16}

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