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# The heliosphere mass variations: 1996–2006

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**Abstract.** The variations of the global mass of heliosphere in the 23rd cycle of the solar activity are described. The results are derived from solar corona observations and from 'in situ' measurements made by the space probes SOHO, VOYAGER2, ACE, WIND, and ULYSSES. It has been revealed that though the total mass of corona fluctuates during the solar activity cycle approximately in a ratio of 1 : 3, the specific mass flow ($q$) in the solar wind does not change in the ecliptic plane. In the polar regions the $q$ decreases during the minimum in a third of the original value and the velocity of expansion is roughly double. These findings are valid for the 23rd solar cycle.

**Keywords.** Sun: corona, interplanetary medium

## 1. Introduction

The space controlled by the Sun through its gravitational force is usually called heliosphere. If we take into account that the distance from the nearest stars is approximately 4 LY, then the radius of the heliosphere would be 2 LY, i.e. $9.46\,10^{12}$ km or 63235 AU. However, heliosphere is usually the space with a diameter of 100−200 AU and the places where the solar and star wind have the same energy density are regarded as the limit of the heliosphere. This space is filled with the matter of the expanding corona solar wind and interplanetary dust as indicated by observations of cometary tails and later confirmed by 'in situ' measurements of space probes. The source of our knowledge about matter distribution in the heliosphere before space missions era was the analysis of observations of the solar corona during total eclipses (K- + F-corona) and the zodiacal light which is an extension of the F-corona. The theoretical basis for such analyses is the knowledge of the mechanisms of light scattering on free electrons (K-corona) and solid dust particles (F-corona and zodiacal light). The second section contains a summary of the results of the analysis and the third section brings information on 'in situ' measurements of proton density and their temperature using space probes. The variations of the heliosphere density in the 23rd cycle of the solar activity (1996–2006) follow from the analysis of the observations of WIND, ACE and SOHO satellites. Conclusions based on this information are presented.

## 2. The density of the solar corona

According to the generally accepted concepts, the light of corona originates from the scattering on free electrons and dust particles. The distribution can be distinguished according to the absorption lines depth in the spectrum. The scattering on electrons prevails closely to the limb, approximately from $\rho = 2.2$ there prevails the scattering on dust particles ($\rho$ is the distance in solar radii). We can estimate the amount of the ionised matter according to the total brightness of corona during total eclipses. This brightness is conventionally estimated in the range of $1.03 < \rho < 6.0$, whereas the unit is $10^6$ of the mean brightness of the solar disc. Fig. 1 brings together the data on total brightness of K-corona during many eclipses. The data are taken from the paper of Rušin & Rybanský (1985) and supplemented by photometric observations carried out in 2001 (Pintér *et al.* 2004) and 2006 (Pintér & Rybanský 2008).

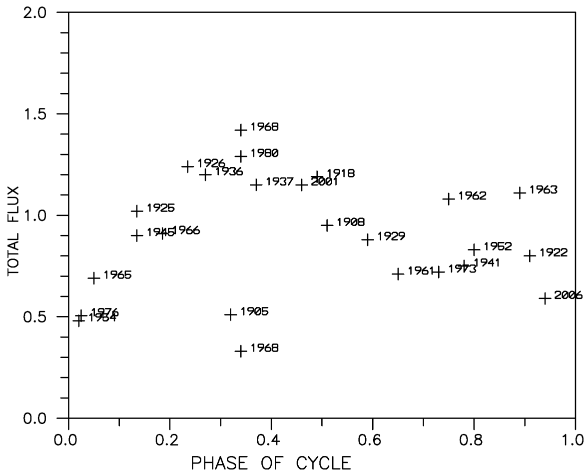


**Figure 1.** The total brightness of K-corona during total solar eclipses. The value is determined from the observed total brightness of corona in the range of $1.03 < \rho < 6.0$ after subtracting the value of $0.3\,10^6$, pertaining to the F-corona.

Fig. 1 shows that the total brightness and hence the total mass of corona within the indicated limits of the distance fluctuates during the solar activity cycle approximately in a ratio of 1 : 3. It corresponds to the analysis of observations of K coronameter at Mauna Loa (Hansen *et al.* 1969). Allen (1976) presented a formula for the mean values of the free-electron density. The newer observations of LASCO 2 and LASCO 3 coronagraphs onboard SOHO indicate that short-term variations may be even larger.

## 3. Density from the in situ measurements

From the 1970s the exploration of the heliosphere has been done by using space probes. The probes HELIOS 1 and 2 approached the Sun to a distance of 0.3 AU, the probe VOYAGER 2 measured some parameters of the heliosphere up to the distance of 84 AU (August 2007). In addition, during their journey, almost all probes determined for the exploration of planets measured the parameters of the surrounding space - heliosphere. However, all these measurements are by far not sufficient for the description of such a huge space. In spite of this, they help to create at least an ordinal idea about its characteristics.

Fig. 2 shows the results of the measurements of proton density as estimated by some space observatories indicated in the Figure. All observations are in the log-log scale concentrating along a line with an inclination of $-2.03$. If the point at issue was only the expansion with constant velocity, the inclination would be $-2$. The change of inclination of the approximation line is probably connected with the recombination of protons because the measured kinetic temperature of protons is at a distance of the Earth $10^5$ K and the measurements of VOYAGER 2 show that at a distance of more than 80 AU the temperature decreases to a value of about $10^4$ K. The amplitude of the measured values is very high, in hourly averages up to 1 : 1000.

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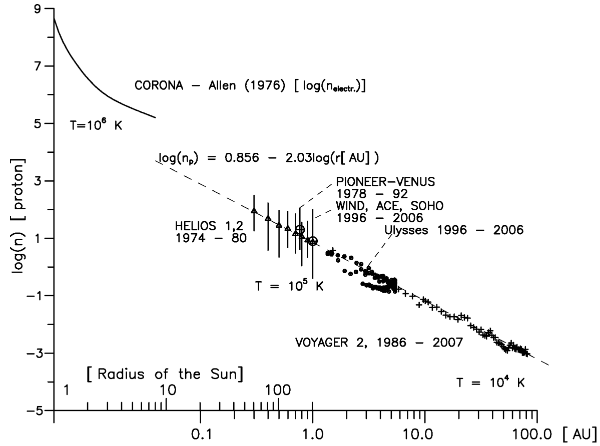


**Figure 2.** The course of proton density in the heliosphere according to the measurements of various space objects. Details are in the text.

Proton densities, measured at the ULYSSES probe that passes above the solar poles, are approximately half, but the velocity of expansion is roughly double: consequently, the specific mass flow $q = v\, n_p$ is approximately the same as in the ecliptic plane.

## 4. Conclusions

On the basis of the analysis of evolution of proton densities and velocities measured by sattelites we can assume that:

A) In contrast to solar corona, none of the parameters at WIND and ACE probes shows dependence on the phase of a cycle. The difference in evolution in Fig. 2 cannot be explained by different amount of protons and electrons (by 11% abundance of helium if the number of atoms is $n_p = 0.9\, n_e$). The mass of the corona increases probably only in the closed magnetic structures;

B) The trend of the constant $q$ appears, because the value of $v$ often increases with decreasing $n_p$;

C) An unexplained increase of $v$ appeared at both probes in 2003;

D) A decrease in both the density and the total flow appears in the cycle minimum at the satellite ULYSSES.

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