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DISCUSSIONS

Variable Solar Wind

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Abstract—The solar wind in the heliosphere is a variable phenomenon on all spatial and time scales. It has been shown that there are two basic types of solar wind by the Strouhal number $S = L/VT$, which characterizes relative variations in the main parameters of the solar wind on the given time interval T and linear scale L for velocity V, which is never zero. The first type is transient ($S > 1$), which is usually the basic type for sufficiently small values of T and large values of L. The second type is quasi-stationary, when $1 > S > 0$. The constant solar wind is nonexistent. The extreme case of $S = 0$ is physically impossible, as is the case of $S = \infty$. It is always necessary to indicate and justify the range of applicability for a special quasi-stationary case $1 \gg S > 0$. Otherwise, to consider the case of $S = 0$ is incorrect. Regarding this, the widely-spread views on the stationary state of the solar wind are very conditional. They either lack physical sense, or have a very limited range of applicability for time T and scale L.

Keywords: solar wind, solar wind types, absence of constant solar wind
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INTRODUCTION

As a physical phenomenon, the solar wind was discovered long before the appearance of its theoretical models and direct observations (Brandt, 1973). A figurative name for this phenomenon (‘solar wind’ in English, ‘Sonnenwind’ in German) appeared in the scientific literature in the early 20th century, however, it did not become established or commonly accepted; at that time and later, the notion of “corpuscular streams” was spoken and written about more often. The fact that it was plasma, with its intrinsic complex collective properties, and not simply separate corpuscles, was understood much later. The first quantitative data on the solar wind were indirect and followed from the observations of comets and their comas, geomagnetic disturbances, and variations of cosmic ray fluxes. The fact that there exists an almost radial stream of plasma spreading from the Sun with supermagnetosonic velocity throughout the heliosphere remains astonishing and still does not have a satisfactory explanation. Until very recently it was supposed that the solar wind could be absent at times and locations, and that plasma constantly existed in the heliosphere, not moving away from the Sun. Until the middle of the 20th century, that was assumed by most experts, including Sydney Chapman, one of the founders of the modern physics of solar–terrestrial connections. It is also reflected in the previous name of the phenomenon, “corpuscular streams from the Sun”. This emphasized the variable, sporadic, and intermittent character of the phenomenon. It is also known that a major expert in solar corona physics I.S. Shklovsky was not convinced of the permanency of this phenomenon even after the first direct measurements of the density and velocity of the solar wind from spacecraft became available (Shklovsky, 1962). More precisely, he believed that the stationary polytropic spherically symmetric model of this phenomenon (Parker, 1958) was based on the erroneous choice of integration constants in the system of three basic equations. This, in turn, was a gross and purely subjective mistake, as we now understand. The word “permanent” in the modern Russian language means “continuous”, “constant”. Without proper clarification, it can lead to misunderstandings when one refers to “discontinuities” or “variability” of the solar wind. However, ambiguity is easily avoided, as soon as numerical characteristics are introduced, such as velocity, density, temperature, functions of particle distribution in the phase space, density of electric and magnetic fields, and other macroscopic and microscopic values.

Because of the rapid progress of knowledge in the space era, after only several decades the permanency of the solar wind is rarely doubted due to obvious factual material, a vast array of direct and indirect observations, and the development of various physical, mathematical, and numerical models of this very important phenomenon. The “revolution” in the mass scientific consciousness happened in mere years in the early 1960s.

However, there is still much unknown about the solar wind, and its studies actively continue using all available observational and theoretical means. For example, it is not known when and how this phenomenon came into existence in the distant past; we can only guess that it happened billions of years ago, in the era when the Sun as a star moved to the main sequence in its evolutionary development, as the thermonuclear chain reactions of exothermic synthesis started in its core. It is not known when and how the solar wind may cease to exist in the future; we suppose that it can happen only after termination of solar activity, which is supported by the energy source in the form of thermonuclear reactions in the core with subsequent transfer of radiation in the radiation zone and magnetoplasma convection near the surface, or if the Sun enters a too dense cloud of matter or a very strong external magnetic field over the course of its motion in the Galaxy. Both scenarios are possible, but the conceivable time scale is still cosmogonic. We do not know in detail how the solar wind originates around the Sun and how it is terminated at the distance in contact with the interplanetary medium. There are many hypotheses on this subject. The picture changes literally before our eyes as new knowledge is acquired. Recent hypotheses that the solar wind was absent during the period of the so-called Maunder minimum in the 17th century quickly became outdated and, as it turned out, they lacked sufficient observational and theoretical basis. Equally, we cannot talk about a total absence of a hot corona during that period, although such prejudices are being overcome with great difficulty and not without hesitation (Gulyaev, 2015).

An important role in considering complex and unsolved questions is played by dimensionless scale analysis. In this work, it is used to clarify the question of possible types of the solar wind from the point of its temporal variability. Apparently, a convenient dimensionless parameter for this is the Strouhal number $S = L/VT$, where L is the characteristic linear scale, V is the characteristic velocity scale, and T is the characteristic time scale (Landau and Lifshits, 1986). The results of this consideration, which are given further, show that the constant solar wind is nonexistent. Such a wind can be spoken about only very conditionally. The solar wind can be considered transient or quasi-stationary, depending on the chosen criteria by the Strouhal number. It is necessary to immediately note the noninvariant character of the Strouhal number, associated with the possibility of choosing a moving reference frame. Thus, the whole further classification appears conditional and relative. Throughout this paper, we talk about the reference frame bound to the fixed center of the Sun. The stationary state can be spoken about if there is such a localized reference frame, in which the partial time derivatives are absent for the physical values of our interest. There are no such conditions on the Sun and around it.

SOLAR WIND TYPES BY THE STROUHAL NUMBER

Estimations of the Strouhal number S for the solar wind in specific situations present no difficulty and thus are not given here. They can easily be obtained for each specific case, as this requires only three steps: (1) indicate the desired scales of time T and length L; (2) take into account that the solar wind velocity (for reasons only partially understood) can vary within wide ranges almost of an order of magnitude, from several hundreds to a few low thousands of kilometers per second, never increasing or decreasing below or above the mentioned limits at the Earth's orbit. What these limits are conditioned by, and whether they can be exceeded with expansion of the available database, is not known to the author. Also unknown are the real limits of other manifestations of solar activity which ultimately serves as a cause of the solar wind; (3) perform a simple arithmetic operation $S = L/VT$.

LARGE STROUHAL NUMBERS

Large Strouhal numbers indicate the presence of short-term processes and very-large-scale structures. The solar wind is nonstationary by its physical nature. Partial time derivatives are as important in its description as spatial nonuniformity, which can be weak, on a scale of the order of an astronomical unit, or strong, with a typical scale approaching the Debye radius or inertial length (for example, in shock waves and numerous kinetic structures, which are replaced by discontinuities in macroscopic description). The picture of the solar wind formation by mutual overlaying of a vast number of individual solitons spreading away from the Sun is noncontradictory. These solitons are difficult to discern and impossible to distinguish from each other, especially at sufficiently large distances, where they mix partially or completely, which leads to a variable nonzero "pedestal" on the charts of velocity–time dependence. Very often this pedestal, without any physical grounds, is called a "quiet" solar wind. This is a very unsuitable term, which is, unfortunately, firmly rooted. It would be simpler and more correct to talk about a "relatively slow wind" in this case and indicate a specific velocity value as a reference point.

SMALL STROUHAL NUMBERS

Small Strouhal numbers indicate that long-term processes and small spatial scales are no less important for a correct understanding and description of the solar wind. To neglect one in favor of the others is a tempting but a misleading way, which is often used, but cannot provide complete understanding of the physical picture of the considered solar wind phenomena. The extreme case of such an unsatisfactory situation is $S = 0$. This is true for the well-known polytropic Parker model, which is sometimes called "classic". This model of a spherically symmetric expansion of the solar wind does not meet the basic law of matter conservation, so it a priori cannot be applied to significantly large time periods. This model of the near-star space is secondary and can be considered together with an earlier accretion model (Bondi, 1952). The only difference between them is in setting the external boundary conditions on the Sun and at the infinity, while their mathematical structure and equations are the same. The radial velocity sign in the resultant Bernoulli law remains undefined constant. For this reason, one cannot in any way assume (although it is still encountered in the literature) that the polytropic model on its own is applicable and sufficient for a physical explanation of the reasons for radial expansion or accretion in the atmospheres of solar-type stars. Apparently, solar-type stars with accretion instead of the wind can exist. The conservation equations do not prohibit that; it is a question of boundary and initial conditions.

Such reasoning could apparently serve as a sufficient basis for much more cautious speculations about the "constant and variable" solar wind streams than is currently done all too often. However, this consideration was not encountered before in a sufficiently explicit form. The author is also not aware of the explanation of the fact that the average density of the solar wind over the whole time of its observations has been estimated as several particles per cubic centimeter, and not tens, hundreds, thousands, or, to the contrary, a small fraction of that. Actually, both opinions were common relatively recently in the past. These hypotheses were ruled out with the acquisition of new knowledge. Currently, we cannot reasonably explain the upper and lower limits of relative changes in the ion composition of the solar wind.

Based on the above considerations, the following noncontradictory explanation of the physical nature of solar wind can be given. The solar wind as a permanent phenomenon occurs as the result of mutual overlaying of the whole set of both well-discerned and indiscernible moving nonuniformities of plasma. The brightest and most noticeable of them are observed as coronal mass ejections. There are no regions of rest between them, as well as no return motions back to the Sun in the heliosphere, although such regions can be seen in the corona at all altitudes. In the heliosphere, it is a solid flow with variable values of velocity, density, and temperature. The main conclusion is that the solar wind is, in principle, a nonstationary and nonuniform physical phenomenon with certain average and extreme characteristics of plasma and electromagnetic fields, whose threshold values are still not fully known and studied. The constant solar wind does not exist.

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