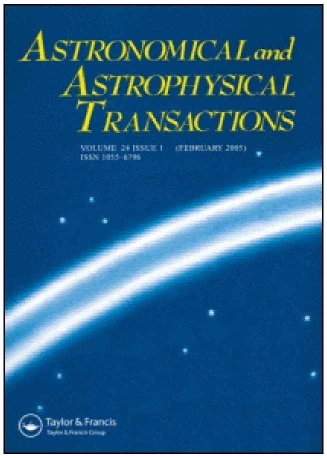
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Diagnostics of solar wind streams

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Up-to-date methods of investigation of solar wind generation are applied to study the types of the streams that form the inhomogeneous jet structure of circumsolar plasma. The particularities of this structure are analysed at the maximum and transition to the declining phase of cycle 23.

Keywords: Sun; Solar wind; Sources and streams

1. Introduction

The spatially inhomogeneous structure of the solar wind has been studied since the 1970s. It is divided into slow and fast solar wind, the latter consisting of streams with a speed $\geq$400 km/s. At present, these studies are continued (*e.g.*, see [1]). The existence of fast solar wind was inferred from the analysis of latitudinal dependence of the solar wind velocity based on scintillation data obtained in the epoch of solar minimum. At high heliolatitudes, the velocity was found to increase up to $\geq$600 km/s [2, 3]. At low heliolatitudes, fast solar wind was revealed in observations of the Helios space mission. It proved to originate from the region occupied by coronal holes [1, 4]. Further progress was associated with a detailed study of the solar wind jet structure. Primarily, regular observations were carried out at large distances from the Sun $R \sim 1$ a.e. [5]. This made it difficult to identify the mechanism of formation of the stream structure. To establish the relationship between the solar wind structure and coronal sources, we need data on the streams in immediate proximity to the Sun. In order to solve this problem, we have developed a method that allows the stream structure to be studied at distances $R \sim 4-70\, R_s$ from the Sun. The method is based on localizing the boundaries of the solar-wind transonic transition region, in which the subsonic plasma flow is changed by a supersonic plasma flow [6].

The study is based on radio occultation data obtained regularly at the Pushchino Radio Astronomical Observatory with the large radio telescopes DKR-1000 and RT-22. Besides

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that, we calculated the structure and intensity of the magnetic field in the vicinity of the source surface ($R \approx 2.5$) and analysed the SOHO/LASCO C2 white-light images of the solar corona.

2. Types and cycle evolution of the solar wind streams

The study of the origin of the solar-wind jet structure depends on the bulk sounding of circumsolar plasma at $R \approx 4-70\, R_s$. The sounding data make it possible to localize the inner boundary of the solar-wind transonic transition region in interplanetary space. The diagnostics are based on the analysis of correlation between the coronal magnetic field $|B_R|$ at the source surface ($R = 2.5\, R_s$) and the location of the inner boundary R_{in}

$$R_{in} = F(|B_R|) \tag{1}$$

Streams of different types manifest themselves as several correlation branches as shown in figure 1. The correlation diagrams for the solar maximum of 2000–2002 are given in [7]. Figure 1 represents new data—the correlation diagrams for the declining phase of the cycle (2003–2004). The conventions used in figure 1 are explained in table 1. Analysis of the correlation diagrams $R_{in} = F(|B_R|)$ for 2000–2004 combined with the calculated coronal magnetic field and structure of the white-light corona reveals different types of streams. As seen from table 1, the type of the stream depends on the magnetic field structure in the solar corona.

A distinctive feature of the solar maximum of 2000–2002 is the appearance of a formerly unknown uncorrelated component in figure 1 denoted as ◇ in table 1, in which the position of the inner boundary is not controlled by the magnetic field $|B_R|$. Another important particularity of the maximum epoch is that the inclination of two slow components of the stream (symbols • and ∘ in table 1) depends on the activity level, increasing with the increase of the latter (figure 2). In the declining phase in 2003–2004, determined by the time dependence of the Wolf numbers $Rz(t)$, the inclination of the slow component • increases unexpectedly and

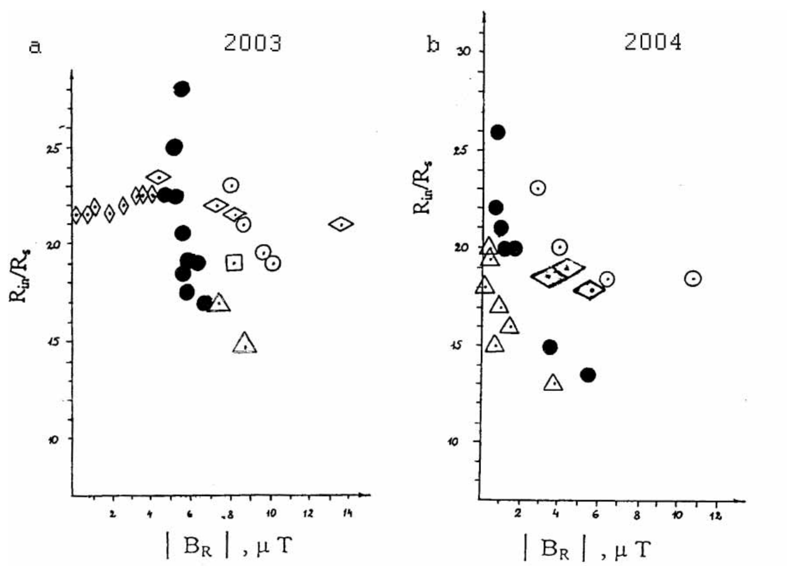

Figure 1. Correlation diagram: location of the inner boundary R_{in} as a function of the magnetic field intensity $|B_R|$ for 2003 (a) and 2004 (b).

Table 1. Structure of the solar wind streams as inferred from the correlation diagrams $R_{in} = F(|\mathrm{B_R}|)$.

N	Type of stream	Magnetic field strength $\lvert \mathrm{B_R} \rvert$	Magnetic field structure	Structure of the white-light corona	Symbol
1	Fast stream	Strong magnetic field	Open field lines	Large CH or polar CH	<>
2	Fast stream	Strong magnetic field	Low loops in very strong magnetic field	Weak diffusion emission	□
3	Fast stream	Weak magnetic field	Open field lines	Local CH or CH neighborhood, between two streamer lobes	Δ
4	Slow stream	Weak magnetic field	High loops	Streamers	•
5	Slow stream	Weak and medium magnetic field	Mixed	Streamer neighbourhood	∘
6	Uncorrelated component: the slowest streams	Weak magnetic field	Very low closed loops or a weak streamer	Zone between the streamer and dark region or very weak streamer	◇

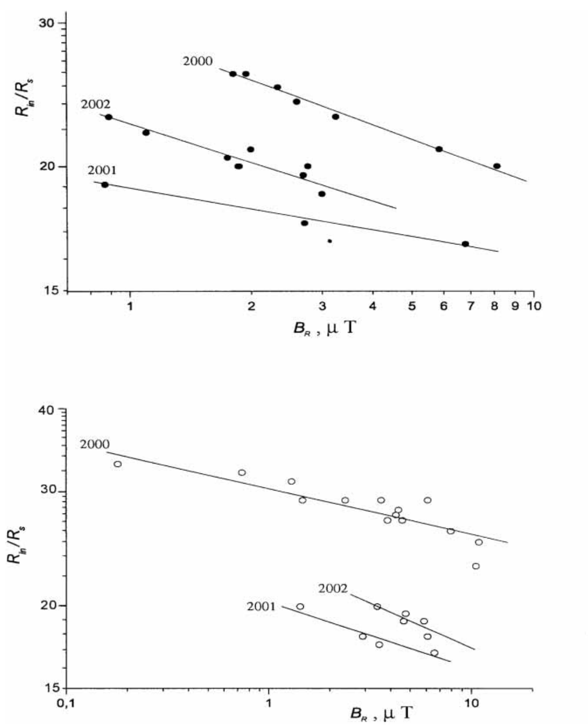

Figure 2. Inclination of the correlation curves $R_{in} = F(|\mathrm{B_R}|)$ for the stream components • (a) and ∘ (b) (according to table 1).

becomes much greater than it was in 2000. The uncorrelated component of the stream (◇ in table 1) typical of the epoch of maximum (2000–2002) is also distinctly pronounced in the 2003 data, but is absolutely absent in 2004. Thus, the peculiarities of the stream structure that appeared at the solar maximum of 2000–2002 were not only conserved, but were also enhanced in the declining phase in 2003–2004. These peculiarities can be understood if we

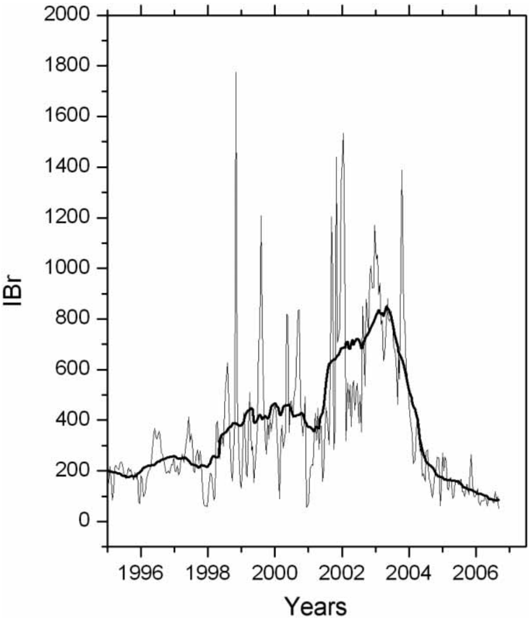

Figure 3. Time dependence of the general intensity of the global magnetic field IBr(t) in the corona at $R = 2.5$Rs.

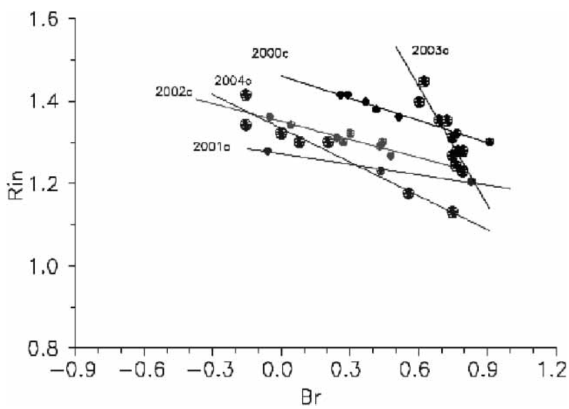

Figure 4. Inclination of the correlation curves $R_{\mathrm{in}} = F(|\mathrm{B_R}|)$ for the stream component • (according to table 1) for 2000–2004.

analyse how the ratio of the fields of different scales changes during an activity cycle. Figure 3 represents the intensity of the solar global magnetic field I_{Br} as a function of time. One can see that I_{Br} reaches its maximum value in 2003. The intensity of the global magnetic field in the solar corona accounts for the high level of activity in 2003 and the observed evolution of the stream structure (see figure 4). Figure 4 illustrates the change of inclination of the slow stream component • in the course of the activity cycle.

3. Conclusion

The main progress in the study of solar wind jet structure has been achieved in the diagnostics of the stream components and their sources in the solar corona. The diagnostics are based on the analysis of the correlation diagrams $R_{\rm in} = F(|B_R|)$, where $R_{\rm in}$ is the location of the inner boundary of the solar-wind transition region determined from radioastronomic experiments and $|B_R|$ is the calculated intensity of the magnetic field at the source-surface $R = 2.5\,R_s$. The experiments carried out during 2000–2004 have revealed streams of six different types in the solar wind structure.

The ratio of the solar magnetic fields of different scales is shown to change significantly in the course of an activity cycle. This infers that the general variation of solar activity and evolution of the solar wind structure is not determined by the time variation of the Wolf numbers alone.

It is found out that the correlation of two slow stream components displays a dependence $R_{\rm in} = F(|B_R|)$ close to the analytical one. The inclination of the correlation curves shows that the intensity of the global magnetic field is the basic factor that contributes to the solar activity and evolution of slow streams in the declining phase of the activity cycle (2003–2004).

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