Scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences (27 May 1992)

Usp. Fiz. Nauk **162**, 155–159 (December 1992)

A scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences was held on 27 May 1992 at the P. L. Kapitsa Institute of Physics Problems. The following reports were presented at the session:

1. *R. A. Gulyaev.* Outer solar corona as an optical manifestation of the heliospheric current sheet.

2. *L. D. Bakhrakh and A. A. Bliskavitskiĭ.* Optical-microwave beam formation methods for superwideband antennas.

Brief summaries of both reports are given below.

R. A. Gulyaev. *Outer solar corona as an optical manifestation of the heliospheric current sheet.*

1. On the basis of its structural properties the solar corona has two distinct parts: an inner part, consisting mainly of loop formations, and an outer part. The main structural element of the outer corona, determining the large-scale global pattern of the corona as a whole, are helmet streamers, which extend far into the interplanetary space. The transition from the inner to outer corona occurs at heliocentric distances r ranging from 1.5 to 2 solar radii ($R_\odot$).

The heliospheric current sheet (HCS) is a surface which separates the polarities of the interplanetary magnetic field (IMF). Intersection of the HCS by the earth or a space probe is perceived as a manifestation of the sectoral structure of the IMF. The configuration of the base of the HCS is described well by the neutral line of the IMF on the "surface of the source" ($r \approx 2.5 R_\odot$), determined by extrapolating the magnetic-field measurements to the photosphere.[1]

Recent investigations have shown that the coronal helmet streamers are not distributed randomly above the sun, but rather they form, in aggregate, a closed belt around the sun and this belt corresponds to the base of the HCS. We can state more definitely that the coronal helmet streamer belt is the visible (optical) manifestation of the HCS near the sun, and the streamers themselves are the structural elements of the HCS (this is discussed in detail in Ref. 2).

In Ref. 2 the concept of the median plane of the HCS was introduced in order to study the evolution of the spatial orientation of the HCS. The position of the median plane, determined by a purely geometric method, for example, from the configuration of the neutral line on the surface of the source, corresponds well to the dipole component of the general magnetic field of the sun.[3] The perpendicular to the median plane, passing through the center of the sun, can be regarded as the axis of the HCS, and the points where this perpendicular intersects the surface of the sun can be regarded as the poles of the HCS or the magnetic poles of the sun.

A number of regularities have been discerned in the changes of the orientation of the HCS during the 11-year cycle of solar activity. In particular, the angle of inclination of the median plane of the HCS with respect to the plane of the solar equator changes from almost zero at the minimum of the cycle to $\sim 70°$ at times ~ 1 yr before and ~ 1 yr after the cycle maximum.[2,4] During an approximately two-year period of maximum solar activity, the configuration of the HCS is so complicated and changes so rapidly that it becomes impossible to determine the median plane and the concept itself of a median plane evidently becomes meaningless.

2. Our analysis showed unexpectedly that during a large fraction of the 11-year cycle the real configuration of the HCS base deviates very little from the median plane.[5] We examined a 15-year time interval which included all phases of the 11-year cycle except for the epoch of the maximum. We found that the standard deviation of the HCS base from the median plane does not exceed 10° for 43% of the time and 15° for 73% of the time. Thus, the HCS base and therefore the helmet streamer belt can be regarded as a largely planar formation. There is probably an analogy between the shape of the corona in three-dimensional space and the shape of spiral galaxies.

The impressive variability of the shape of the solar corona is well known. At the minimum of the 11-year cycle the corona has two systems of helmet streamers, extending along the equator; at the maximum the helmet streamers are distributed more or less uniformly over the entire halo of the sun. As the cycle minimum passes into the cycle maximum the shape of the corona should, according to the standard ideas, gradually evolve from one extreme form to another. Many attempts have been made to classify the structure of the corona in terms of the phase of the 11-year cycle, but a completely unequivocal relation between these two phenomena has never been found.

Our result that the outer corona is nearly planar makes it possible to construct a new picture of corona evolution during the 11-year cycle: During a large fraction of the cycle the shape of the corona in three-dimensional space does not change much and the observed diversity of coronal shapes is determined mainly by changes in the orientation of the corona with respect to the observer.[5]

This picture is a first approximation, describing the most general properties of the global structure of the corona. Of course, the real picture is richer. In particular, during one-fourth of the time period considered the standard deviation of the HCS base from a plane is greater than 15° and reaches 45°. This is mainly due to the contribution of the intensified quadrupole component of the magnetic field and the four-sector structure of the IMF in the ecliptic plane could be a consequence of this situation. We can provisionally call the "planar" state of the corona, existing during a large part of the 11-year cycle, the ground state (by analogy to atomic systems) of the corona; all other states can be called excited states.

 0038-5670/92/121083-03$03.00

3. So, the appearance of the corona is largely determined by the corona orientation with respect to the observer. Two limiting cases of orientation are of special interest. In the first limit the corona is oriented parallel to the line of sight, i.e., it is observed "edge-on." For the epoch of the cycle minimum this situation is typical: the HCS and the outer corona lie close to the plane of the solar equator and for this reason they are always oriented edge-on. This determines the characteristic shape of the "minimal" corona. But, even when the HCS makes a large angle with the plane of the equator a similar picture should always reappear regularly when the corona, rotating together with the Sun, turns edge-on toward the observer. Obviously, under favorable conditions this should happen twice during each revolution of the sun.

If a total solar eclipse occurs at this moment, the observer should see an interesting picture: a corona of the "minimal" type, making an angle with the equator. Such a situation occurred during several eclipses. But the most effective picture was apparently observed during the July 11, 1991 eclipse, when the median plane of the HCS made an angle of up to 67° with the equator. Figure 1 displays a drawing of the structure of the 1991 corona. This drawing is based on observations performed, as part of the expedition of the USSR Academy of Sciences in Mexico, by a group from the Institute of Terrestrial Magnetism, the Ionosphere, and Radio Wave Propagation.[6] The drawing also shows the section of the sun's surface by the median plane of the HCS, calculated from the Stanford data on the neutral line on the surface of the source.[7] The angle between the line of sight and the median plane was only 18°, i.e., the corona was observed almost edge-on.

The 1991 eclipse occurred in the epoch close to the maximum of the 11-year cycle. For this reason, on the basis of the standard ideas, one would expect the corona to have a shape close to the "maximal" shape. Figure 1 shows that the shape of the 1991 corona does not at all correspond to the "maximal" type, but rather it is close to the "minimal" type with a very steep angle with respect to the equator. Thus Fig. 1 demonstrates that in application to the 1991 corona the existing ideas about the evolution of coronal shapes are unsound. At the same time, the above-described picture fits very well within the concept of a "planar corona" and can serve as a direct experimental confirmation of this concept.

4. The other limiting orientation is even more interesting and informative: a planar solar corona lying in the picture plane. It is obvious that in this case the magnetic pole must be located near the center of the solar disk. Since in order to realize such an orientation the inclination of the corona with respect to the equatorial plane must be very steep, this situation, in contradistinction to the edge-on case, is possible only during premaximal and postmaximal phases of the 11-year cycle.

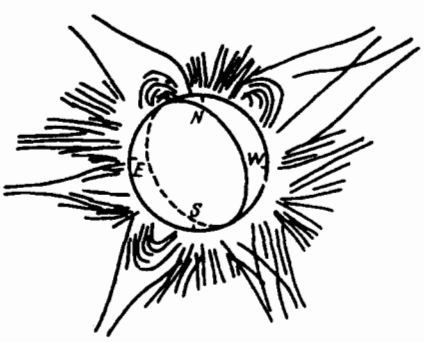

FIG. 1. Structure of the July 11, 1991 solar corona.

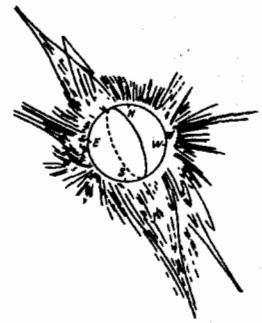

FIG. 2. Structure of the June 19, 1936 solar corona.

Observations from the side of the sun's magnetic poles, when the corona lies in the sky plane, give a view of the heliosphere sheet "from above," realized from the earth. Such observations can give very significant information about the detailed structure of the HCS near the sun and its relation to specific formations on the sun. In particular, answers can be obtained immediately to such questions, for example, as how many helmet streamers are contained in the current sheet and how the streamers are distributed along the neutral line. It is important that the different coronal details along the line of sight, occurring with other aspect angles of the corona, are not superposed in this case or the superposition is reduced to a minimum.

Analysis of corona orientation during total solar eclipses observed in the 20th century has shown that the picture corresponding to a planar pattern, lying in the sky plane, has never been realized in its pure form. The largest inclination to the equatorial plane occurred on the July 11, 1991 (67°) and June 19, 1936 (68°) eclipses. The 1991 case is described above. A picture of the structure of the 1936 corona, based on the data of A. T. Nesmyanovich,[8] is presented in Fig. 2. During this eclipse the angle between the line of sight made an angle of 45° with the median plane of the HCS, i.e, the corona lay midway between the two possible limiting positions: edge on and en face. The picture nonetheless gives a completely clear idea of the shape of the corona "in the plane." In the context of what we have said above, the importance of observations of all total solar eclipses becomes obvious.

5. Another important direction of optical research on HCS and the exterior corona is the search for remote coronal streamers in the night sky. The solution of this problem would give a direct optical record of the HCS at large distances from the sun in a wide range of heliographic latitudes. The question of observations of coronal streamers in the night sky was first raised by G. M. Nikol'skii back in 1956,[9] whose attempts at the time to observe streamers were unsuccessful. Now, with the existence of modern observational

techniques, we can return to this important problem.

The highest angular distance from the sun up to which coronal streamers could be observed is $50R_\odot$ or 12.5° (photographs made by astronaut Warden on the Apollo 15 moon ship[10]). The start of the astronomical night corresponds to the sun setting below the horizon at 18° ($\sim 70R_\odot$).

Estimates show that it is in priniciple possible to observe coronal streamers above the horizon up to distances of 40–50° from the sun. An important property of remote coronal streamers (which should make it easier to observe them) is their high degree of polarization in the tangential direction.

V. V. Migulin, N. Ya. Vanyarkha, M. P. Fat'yanov, and B. P. Filippov contributed to the research described in this report. I am sincerely grateful to them all.

[1]J. T. Hoeksema, Adv. Space Res. **9**, 141 (1989).
[2]R. A. Gulyaev and N. Ya. Vanyarkha, Solar Phys. **140**(2), 369 (1992).
[3]N. Ya. Vanyarkha, Soln. dannye, No. 12 (1991).
[4]J. T. Hoeksema, Adv. Space Res. **11**(1), 15 (1991).
[5]R. A. Gulyaev, Solar Phys. **138**(1), 209 (1992).
[6]R. A. Gulyaev and B. P. Filippov, Dokl. Akad. Nauk SSSR **322**, 268 (1992) [Sov. Phys. Dokl. **37**(1), 4 (1992)].
[7]Solar-Geophysical Data, No. 566 (1991).
[8]S. K. Vsekhsvyatskiĭ [Ed.], *Solar Corona and Corpuscular Radiation in Interplanetary Space* [in Russian], Kiev University Press, Kiev, 1965.
[9]G. M. Nikol'skiĭ, Astron. Zh. **33**, 588 (1956).
[10]D. C. Wilson and R. M. MacQueen, J. Geophys. Res. **79**, 4575 (1974).

Translated by M. E. Alferieff