THE SOLAR CORONA: FLAT FORMATION

R. A. GULYAEV
Laboratory of Solar Activity, IZMIRAN, Academy of Sciences,
142092, Troitsk, Moscow Region, Russia

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ABSTRACT. During the greater part of the 11-year sunspot cycle the solar corona represents largely a similar flat formation as in the minimum (looking like a galaxy). The observed variety of coronal forms is mainly due to variations of the corona's orientation as seen from the Earth. Two limiting cases of coronal orientation are discussed: perpendicular to the plane of the sky ('edgewise' towards the observer) and parallel with the plane of the sky. The first case is illustrated with the coronal observations of 11 July, 1991. The second case provides an opportunity to observe the corona from above the solar magnetic poles.

The solar corona is known to change its form in an impressive way during the 11-year sunspot cycle. There have been repeated attempts to classify coronal structures in dependence on the phase of the sunspot cycle. But an unambiguous relation between the two phenomena has not yet been revealed. A weak point of such studies may be the absence of a guiding physical idea. It seems that presently the situation is changing and therefore we may approach the subject of the coronal shape evolution from a new point of view.

Many recent investigations have shown that helmet coronal streamers are not distributed randomly. Instead, they form a closed belt around the Sun, and this belt is the base of the heliospheric current sheet (HCS). The configuration of the HCS base is well represented by magnetic neutral line at the source surface (Hoeksema, 1989).

We have studied recently the evolution of the spatial orientation of the HCS in terms of a HCS 'mean plane' which fits the dipole component of the magnetic field at the source surface (Gulyaev and Vanyarkha, 1992). The analysis of the HCS mean plane indicated unexpectedly that the actual configuration of the HCS deviates only little from a plane during most of the sunspot cycle. Figure 1 presents a histogram of the root-mean-square deviation δ of the real HCS configuration from the mean plane. Each individual value of δ refers to one specific Carrington rotation of the Sun. In total 194 rotations of the Sun have been analysed for the periods of October 1971 to December 1978 and October 1980 to January 1989. This whole time interval of more than 15 years involves all phases of the sunspot cycle, excluding 2 years around the solar maximum. The reason for this omission is that the configuration of the HCS near the so-

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lar maximum is so complicated and changes so rapidly that a determination of the mean plane become impossible and the very definition of 'mean plane' apparently loses sense.

The histogram shows the following: during 43 % of the time the RMS deviation of the HCS from the plane does not exceed 10°, and during 73 % of the time δ does not exceed 15°. Therefore, the HCS base and, consequently, the coronal streamer belt can be treated as an essentially flat formation. And since just the system of large coronal streamers is the main component of the global large-scale coronal structure we conclude from the above that during the greater part of the sunspot cycle the solar corona is approximately as flat as it is during minimum. Therefore the observed variety of coronal forms should first of all be due to the diversity of the coronal orientation against the Earth. A certain analogy may thus be suggested between the 3-D coronal view and the shape of spiral galaxies.

This conclusion allows us to formulate a new view on the coronal evolution: in 3-D space the shape of the corona changes only little during the sunspot cycle but the observed evolution of the coronal shape is related largely with variations of the coronal orientation towards the observer.

The above statement should be treated just as a first approximation characterizing the most general properties of the global coronal structure. The real pattern is certainly richer. Also, during about a quarter of the time considered the RMS deviation δ exceeds 15° and may amount up to 45° ('tail' of the histogram). This is due mainly to the enhanced quadrupole component contribution. (One of consequences of that contribution is the 4-sector IMF structure in the ecliptic plane). We can describe the 'flat' shape of the corona which exists during most of the sunspot cycle as the coronal ground state (by analogy with atomic systems) while all other shapes as described as excited states. Note that we do not deal here with the inner corona where loops and arcs are predominant structures.

So, according to the above concept the appearance of the corona is dictated by its orientation relative to the observer. Two limiting cases of orientation are of special interest. The first: corona is turned along the line-of-sight, i.e. it is observed 'edgewise'. Such a situation is typical for the sunspot minimum epoch: during this time the HCS and corona are located near the solar equator plane so they are always turned essentially egdewise towards the Earth. That is why the 'minimum' corona is of a well-known specific form. But even with greater tilts of the HCS a similar pattern should be regularly repeated every time when the corona, rotating together with the Sun, happens to be turned edgewise towards the observer. Such events should evidently happen twice during each solar rotation under the appropriate conditions.

If in such a case a total solar eclipse occurs the observer should witness an interesting picture: a 'minimum' type corona inclined against the equator. Earlier, we have presented a drawing of the corona of the 1932 eclipse as an example of such a pattern (Gulyaev

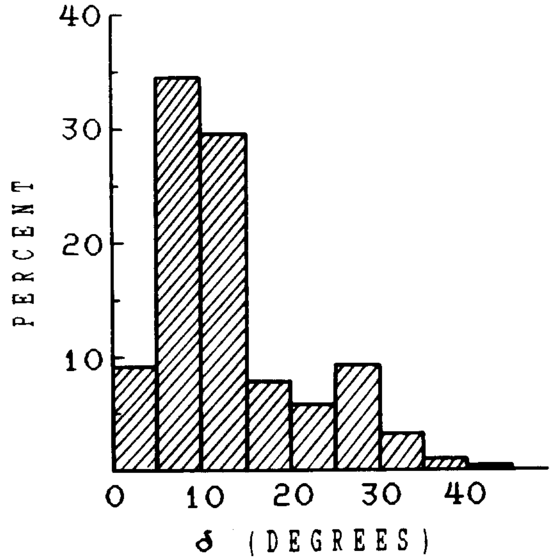

Fig. 1. Distribution of the occurrence of the RMS deviation (δ, degrees) of the HCS base from a mean plane. During 73 % of the time the δ does not exceed 15°.

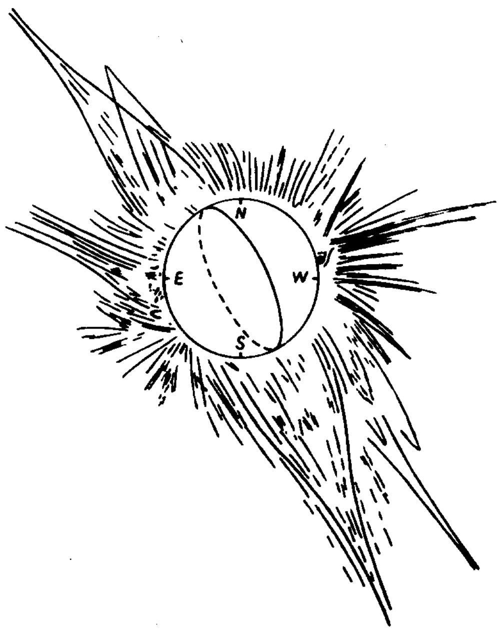

Fig. 2. Structural drawing of the corona for 11 July, 1991 (Gulyaev and Filippov, 1992). The solar magnetic equator is also shown.

and Vanyarkha, 1992). Another case of the above kind took place during the eclipse of 11 July 1991. Figure 2 represents a drawing of the coronal structure based on results of our observations in La Paz, Mexico (Gulyaev and Filippov, 1992). In Figure 2 we also show the section of the solar surface by the HCS mean plane (equator of the solar magnetic dipole) during the eclipse. The mean plane orientation was calculated with Stanford data on the neutral line at the source surface (*Solar-Geophysical Data*, 1991, No. 566). During the eclipse time the inclination of the HCS mean plane against the equator was rather great: 67°.

Note that the corona at the time of the eclipse has been oriented not exactly edgewise; the angle between the line-of-sight and the HCS mean plane was equal to 18°. However this is a comparatively small angle and that is why we have a pattern very near to that described above: a corona of the minimum type, strongly inclined towards the equator. So Figure 2 provides us direct observational confirmation of the reliability of the 'flat corona' concept presented here.

The situation described above and presented in Figure 2 is impressive. But more interesting and informative is another limiting case of the orientation: the flat corona lying in the plane of the sky or, in other words, the corona fronting towards the Earth. In such a case the solar magnetic pole should evidently be located near the centre of the Sun's disk. Since such an orientation of the corona requires a very steep inclination against the solar equator, this case can only happen at phases just prior to and after maximum of the sunspot cycle (Hoeksema, 1991; Gulyaev and Vanyarkha, 1992).

Solar astronomers have for a long time been dreaming of looking at the corona 'from above', namely from the Sun's polar sides. Finally, the special spacecraft 'Ulysses' has been launched in 1990 with the aim to pass over the solar poles in 1994 and 1995. But it is apparently possible to see the corona from the magnetic polar side while remaining at the Earth. Of course, this is related to the fact that the magnetic poles may change in position.

And although ground-based or circumterrestrial space-born observations cannot completely replace experiments like the Ulysses, they can yield important information on the corona and heliospheric sheet when lying in the plane of the sky (as it was frontward). Such observations may provide answers to questions such as: how many helmet streamers contains the heliospheric sheet and how are these helmets distributed along the neutral magnetic line.

References

Gulyaev, R.A. and Vanyarkha, N.Y.: 1992, *Solar Phys.*

Gulyaev, R.A. and Filippov, B.P.: 1992, *Doklady Akademii Nauk* **322**, 268.

Hoeksema, J.T.: 1989, *Adv. Space Res.* **9**, No. 4, 141.

Hoeksema, J.T.: 1991, *Adv. Space Res.* **11**, No. 1, 15.