# Structure of the Solar Corona

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ABSTRACT. Our recent understanding of the structure of the solar corona is reviewed, with an emphasis on the ground-based observations.

## 1. INTRODUCTION

Our knowledge on the structure of the solar corona has dramatically increased with the advent of X-ray observations from space, especially by the Skylab experiment. The solar corona seen in X-rays clearly demonstrates the magnetic structuring. The magnetic field provides the heating mechanisms, and the magnetic confinement of the heated plasma creates the closed magnetic structures (loops or arcades) in the corona. The open magnetic field lines which are connected to the interplanetary space lead to the coronal streamers and the coronal holes.

Unfortunately, X-ray observations have been carried out only intermittently. On the other hand, ground-based observations provide more continuous coverage of data. For example the intensities of the K-corona and the coronal emission lines have been monitored by using coronagraphs for many years. Spectroheliograms of He I 10830Å line and radio maps also give us information on the coronal structures. This review mostly discusses the recent results on the structure of the solar corona by means of ground-based observations.

## 2. SOLAR CYCLE VARIATIONS

A 'Butterfly Diagram' can be constructed based on the coronal green line intensities monitored for several solar cycles (Hiei and Okamoto, 1988). In a broad sense the coronal Butterfly diagram resembles the sunspot Butterfly diagram. As was pointed out by Waldmeier(1964), however, coronal Butterfly diagram contains poleward migrating branches in the high latitude zones. This feature is also inferred from the migration of polar crown prominences. Leroy and Noens (1983) plotted the standard deviation of yearly green line intensities and revealed the existence of high-latitude branches unambiguously. Coronal emission in



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the high latitude zones will come from the streamers which extend above the polar-crown prominence belts. Therefore the poleward migration of these branches reflects the dynamo process of reversing the polar magnetic field of the Sun.

Another important aspect of the solar cycle variation is the population of X-ray bright points (XBPs), which may correspond to small concentrations of magnetic fields. Davis (1983) summarizes the XBP number count available to date. Strikingly, there are more XBPs near activity minimum than near activity maximum. Based on this, Golub et al. (1979) conjectured that the decrease in the sunspot magnetic flux near the activity minimum might be compensated for by the XBP-associated magnetic flux. However this argument does not hold quantitatively. Total magnetic flux as measured at Mt. Wilson (Howard and LaBonte, 1981) shows that there is more magnetic flux on the Sun in the activity maximum.

## 3. MAGNETIC FIELD CONFIGURATION IN THE CORONA

The magnetic field in the corona is hard to observe directly. Therefore the magnetic field configuration in the corona is usually inferred by extrapolating the magnetic field measured at the photospheric level. The simplest assumption adopted is that there is no electric current in the corona (viz. current-free modeling). The correspondence between the calculated current-free field lines and the coronal loop structures is generally satisfactory (Sakurai and Uchida, 1977).

The rotation of the Sun makes the coronal structures to be seen from various directions. Therefore the three-dimensional shape of stable coronal structures can be reconstructed stereoscopically. Berton and Sakurai (1985) determined the three-dimensional shape of coronal loops by using this technique.

For more global magnetic structures extending beyond 1 $R_\odot$ or so, the effect of the solar wind on the magnetic field becomes important. Such effect is approximately taken into account in the so-called source-surface modeling. This model revealed the correspondence between the open magnetic fields and the coronal hole regions (Levine et al.,1977).

## 4. ROTATION OF CORONAL STRUCTURES

Daily record of coronal intensities observed by coronagraphs can be used to deduce the rotation speed of coronal structures. The differential rotation thus obtained is flatter (i.e. close to rigid rotation) than the sunspot differential rotation law (Antonucci and Dodero, 1979; Parker et al., 1982; Fisher and Sime, 1984). Coronal holes show almost rigid rotation (Bohlin, 1977).

Hoeksema and Scherrer (1987) showed that the coronal magnetic field expected from the observed photospheric magnetic field by means of the source-surface modeling exhibits nearly rigid rotation. Wang et al. (1988), following the evolutional modeling of surface magnetic field initiated by Sheeley et al. (1985), also found the same results. That is, global configuration of the corona reflects the large-scale components of the surface magnetic field, which rotate nearly rigidly. The reason why the large scale magnetic fields rotate rigidly remains yet to be explained.

## 5. CORONAL HOLES

In considering the influence of the solar wind on the environment of the earth's magnetosphere, it is important to constantly monitor the coronal holes. This has been done by using the infrared line of Helium at 10830Å. The energy levels involved in this transition will populate according to the XUV radiation from the corona. Therefore active regions show stronger absorption and coronal holes show less absorption. X-ray images and He 10830Å images are positive and negative photographs of the corona, so to speak.

The other method is to make use of radio observations. Generally the coronal holes appear as depressions in the radio maps. Kundu et al. (1987) found that the position of a coronal hole shifts eastward as they observe it in lower frequencies (i.e. higher in the corona). This might suggest the Archimedian spiral of magnetic field lines bending toward east, but the magnitude of the shift is too large as the authors pointed out. Kosugi et al.(1986) found that the polar coronal holes observed at millimeter wavelengths are brighter than the surroundings. This may be interpreted as due to the existence of polar faculae.

## 6. X-RAY BRIGHT POINTS, MAGNETIC BIPOLES, AND HELIUM DARK POINTS

XBPs are visible in He 10830Å spectroheliograms as dark points (HDPs). As is expected from the mechanism of providing He 10830Å absorption by XUV radiation, the correspondence between XBPs and HDPs is generally good. Golub et al.(1977) claimed that XBPs are formed above ephemeral active regions (ERs), viz. small and short-lived bipolar magnetic fields. However ERs are more numerous near the activity maximum (Harvey, 1985), which contradicts the solar cycle variation of XBPs.

Harvey (1985) showed that about one-third of HDPs are formed above ERs(=small bipolar regions), but the rest of dark points are found where opposite magnetic polarities encounter by chance. Therefore two-thirds of HDPs do not correspond to 'genuine' magnetic bipoles. This latter component may be more numerous near the activity minimum in which a more mixed appearance of magnetic fields is seen.

Kundu et al. (1988) observed bright points in the microwave range (MBPs) and found that some bright points are found above networks where the magnetic field is presumably unipolar. Such bright points may correspond to clumps of network magnetic fields. Note that microwave observations see the chromosphere and the transition region. Network magnetic fields will become diffuse in the corona so that no X-ray conterpart of unipolar microwave bright points will be seen. On the other hand HDPs may form due to XUV radiation from the corona as well as from the transition region. Therefore the possibility is that not all HDPs are XBPs and network bright points also show up as HDPs. The expected relation

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among several features could be as in Figure 1.

## 7. OUTLOOK

Because of the lack of persistent X-ray observations from space, recent observational progresses concering the solar coronal phenomena have mostly been brought by the ground-based observations. We hope that the soft X-ray observations in the 1990's (Solar-A project of Japan-USA-UK, SXI project of NOAA/USA) will give us a big step toward better understanding of coronal physics.

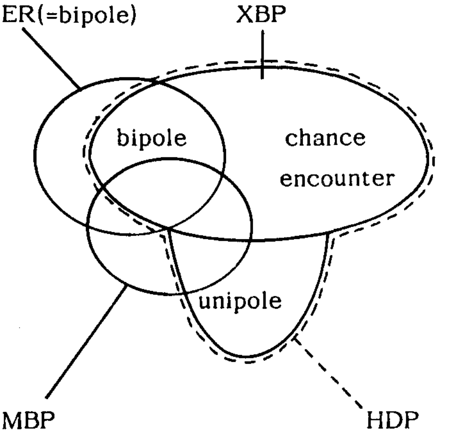


Fig.1. XBP, HDP, MBP and ER.

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