A CORONAL HOLE AND ITS IDENTIFICATION AS THE SOURCE OF A HIGH VELOCITY SOLAR WIND STREAM

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Abstract. X-ray images of the solar corona, taken on November 24, 1970, showed a magnetically open structure in the low corona which extended from N20W20 to the south pole. Analysis of the measured X-ray intensities shows the density scale height within the structure to be typically a factor of two less than that in the surrounding large scale magnetically closed regions. The structure is identified as a coronal hole.

Since there have been several predictions that such a region should be the source of a high velocity stream in the solar wind, wind measurements for the appropriate period were traced back to the Sun by the method of instantaneous ideal spirals. A striking agreement was found between the Carrington longitude of the solar source of a recurrent high velocity solar wind stream and the position of the hole.

Solar wind bulk velocity and photospheric magnetic field data from the period 1962–1970 indicate the possible extension of the result to the interpretation of long term variations in the wind pattern.

1. Introduction

Periodicities of approximately 27 to 28 days duration observed in the solar wind bulk velocity (Snyder and Neugebauer, 1966) and in the interplanetary magnetic sector structure (Wilcox, 1968) suggest that there should be a link between these features and conditions in the low corona. There has, however, been a lack of success in finding consistent experimental evidence of that link (Snyder and Neugebauer, 1966; Couturier and Leblanc, 1970; Pathak, 1971). The major difficulty in such studies lies in the fact that neither the sources of the wind streams nor the location of the critical point are known. If the former could be predicted theoretically and the results merely verified by observation of a large number of events, then the correct extrapolation of wind streams back to the Sun would present no problem. Alternatively, if the velocity profile of the wind as a function of radial distance from the solar surface were accurately predictable, the extrapolation of individual streams back to the Sun could be carried out with confidence and their sources located.

There are a number of workers (Billings and Roberts, 1964; Davis, 1965; Pneuman and Kopp, 1971; Gosling *et al.*, 1972; and Pneuman, 1973) who have suggested that high velocity streams in the solar wind might originate from magnetically open regions in the corona rather than from regions of elevated coronal temperatures. Furthermore, there are now recognized to be a new class of feature in the solar corona, called

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coronal holes, which have many characteristics which are the antithesis of active regions (Munro and Withbroe, 1972; Altschuler and Perry, 1972; Altschuler *et al.*, 1972). When seen in soft X-ray wavelengths they appear as a marked reduction in coronal emission surrounded by coronal structure which has the appearance of a diverging magnetic field configuration.

Since these features apparently have the properties required for the production of high velocity solar wind streams, one example of a coronal hole, seen in soft X-ray solar images, has been compared with a stream source location inferred from solar wind observations for the period. In the absence of the additional X-ray observations of such features, required for a statistical proof of the hole-stream relationship, evidence supporting the extrapolation technique used is cited from theoretical studies of non-linear solar wind equations as well as from recent applications of the mapping of low energy solar particle events.

2. The Structure of a Coronal Hole

A. INFERRED MAGNETIC FIELD GEOMETRY

The development of high resolution X-ray imaging techniques (Vaiana, 1970; Krieger *et al.*, 1970) has enabled the density and temperature structure of the lowest levels of the solar corona ($r \leqslant 1.2\ R_0$) to be studied extensively. The X-ray image of the solar corona taken on March 7, 1970 was compared (Van Speybroeck *et al.*, 1970) with a nearly simultaneous radial density gradient white light exposure (Newkirk and Lacey, 1970). Detailed examination showed that the typical tubular loop structures on the X-ray image extended out far into the low corona, particularly in the vicinity of active regions and filaments. In some cases (the closed 'helmet' streamers) the loops reach heights of between 1.0 and 1.5 R_0 before being distorted into a radially streaming configuration by the expansion of the gas.

A typical soft X-ray image of the solar corona, taken during a sounding rocket flight on November 24, 1970, is shown in Figure 1. Active regions are seen as brightly emitting, highly structured areas and are somewhat over-exposed in this picture. Also apparent are the much larger scale, diffusely emitting structures linking both widely separated active regions and areas of moderately intense unipolar magnetic fields. High loop structures ($h \sim 0.2\ R_0$) are seen associated with a large quiescent filament in the northern hemisphere and with the fragmentary remains of a filament in the SE quadrant of the disc.

It may be seen from Figure 1 that in the vicinity of active regions and over large areas of the solar surface the lower corona has a closed loop configuration. This implies both inhibited coronal expansion and inhibited radial heat conduction in these regions. There are however certain areas of the disc which appear almost free from any transverse field constraints. In particular we note the large area of reduced X-ray emission, a 'hole' in the corona, situated somewhat to the west of central meridian, extending from N20W20 to almost the south pole. An expanded view of this region together with Hα and Ca K photographs of the underlying chromosphere and a Kitt Peak